COST Action 354 - Performance indicators for Road Pavements

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COST 354
Performance Indicators for Road Pavements

WP 4 “Development of a general performance indicator”

Report

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Development of a general performance indicator

Report

INTRODUCTION

COST Action 354 - Performance Indicators for Road Pavements started in April 2004.
The main objective of the Action is the definition of uniform European performance indicators and indices for road pavements taking the needs of road users and road operators into account.

A quantitative assessment of individual performance indicators provides guidance regarding present and future needs in road pavement design and maintenance at both the national and the European levels. By specifying limits and acceptance values for individual performance indicators minimum standards can be laid down for both existing and planned road pavements.

Individual performance indicators can be used for the calculation of combined performance indices that will allow to classify the road with respect to certain characteristics, such as riding comfort, road safety, structural capacity or environment.

These combined indices may be used for the definition of a General Performance Indicator (GPI) that describes the road pavement performance within a single index. The application of a GPI will allow the specification of minimum standards for European roads, and provide effective performance assessment tools for road authorities. The GPI can also be used as input to pavement management systems (PMS) for the analysis of maintenance needs in road networks and optimisation of investments.

For a Europe-wide harmonization of road pavement standards it appears useful and appropriate to specify pavement characteristics in terms of uniform “performance indicators” for different road categories (motorways, national roads, local roads, etc.).

This report describes the work carried out in Work Package 4 (WP 4) “Development of a general performance indicator”. The objective of WP 4 is to develop a General Performance Indicator (GPI), taking the work performed by previous work packages as a basis. The work is divided into different steps, starting with a review of GPIs included in COST 354 database and GPIs reported in the literature, followed by the selection of a function for the calculation of GPI from a set of Combined Performance Indicators (CPI) proposed by WP3. Information on the relative importance of each CPI was gathered through a questionnaire distributed among road administrators, operators, users and researchers. Based on the evaluation of given datasets, in combination with a detailed sensitivity analysis, recommendations for application of the procedure are issued.

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SECTION 1: DEFINITION OF A GENERAL PERFORMANCE INDICATOR

A General Performance Indicator is a mathematical combination of single and/or combined indices which describe the pavement condition concerning different aspects like safety, riding comfort, structural adequacy and environment.

The general indicator (GPI) gives a first impression of the overall pavement condition at network level, and points out weak sections. By using this information a general maintenance strategy can be derived. Consequently the general indicator is a useful tool for superior decisions-makers to assess the general condition of the network and to evaluate future strategies and the funding.

As a general indicator does not reflect the cause of the lack of quality in detail, a more detailed analysis based on single performance indicators has to be performed to assess the maintenance work itself and the necessary financial budget.

The objective of Work Package 4 of the COST-Action 354 “Performance Indicators for Road pavements” is to define a procedure for calculating a General Performance Indicator for road pavements, taking the needs of road users and road operators into account. This work was built on the output of Working Group 2 of the action, which selected and assessed Single Performance Indices (PI) that can be calculated from commonly available Technical Parameters (TP), and subsequently Working Group 3, which developed a procedure for calculating Combined Performance Indices (CPI) that represent aspects of pavement performance that are relevant to road users and road operators, such as safety, riding comfort, structural adequacy and environment.

The work of Working Groups 2, 3 and 4 has been informed by analyses of a database of the types of data collected and indices used in Europe, which was compiled by Working Group 1, as well as additional literature studies. These relationships are summarised below in Figure 1.

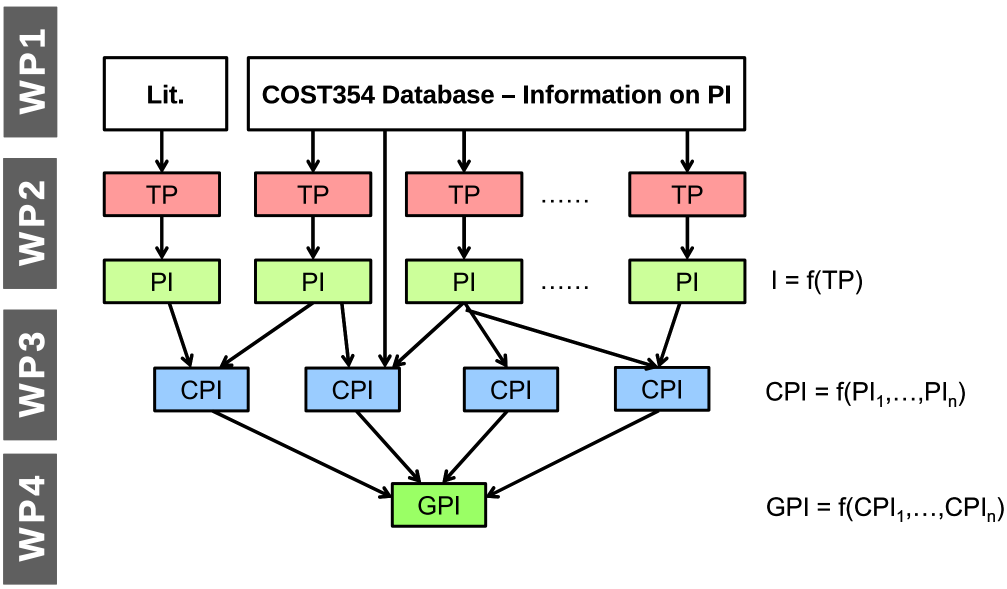

Figure 1 - Overview of the development of performance indicators in the COST 354 database

Each CPI developed by WP 3 is expressed by a dimensionless index on a scale 0 (good condition) to 5 (poor condition). The task of WP 4 is to develop a procedure for combination of the 4 CPI into one General Performance Index, which will also be expressed on a scale of 0 to 5.

SECTION 2: CURRENT PRACTICES FOR ESTABLISHING GENERAL PERFORMANCE INDICATORS

2.1 ANALYSIS OF THE COST 354 DATABASE

General Performance Indicators (GPI) are provided in the COST 354 database as part of the “Combined Performance Indicators” (CPIs). Detailed description on availability of Combined CPIs is provided in WG 3 Final Report. This section provides description of just a few GPIs available in the COST 354 database.

There are two typical approaches in the development of general indices.

The first approach is similar to the approach of COST 354 action and consists of developing combined indices for safety and comfort and structural adequacy, ,based on single performance indices, and then combining these two into the GPI. This approach is used in Austria, Germany, and to some extent in Italy.

The second approach consists in calculation of deduct points based on individual distresses and corresponding weights and deduction of sum of deduct points from the predefined index value for the new pavement (typically 100). This approach is used in Poland.

Austria and Germany are using similar approaches in developing a GPI.

Austria
Austria is using a Total Condition Index (TCI), that is obtained from two combined indices:

- Structural Index (SI) (that is function of SI_Condition and SI_Age)
- Comfort and Safety Index (CSI)

The expression is:

TCI = max (CSI, 0.89*SI)

The Total Condition Index is used at network level, on motorways and primary roads only. The scale is 1 (very good) to 5 (very poor).

Germany
Germany is also using Total Condition Index (GW) that is obtained from two subindices

- Substance subindex (TWSUB) (structural index)
- Comfort and safety subindex (TWGEB).

The expression is:

GW = MAX(TWGEB;TWSUB)

The GW index is used for network level analysis on all road categories. The scale goes from 1 (very good) to 5 (very poor) and there are 8 condition classes.

Italy

Italy uses a Quality Index (Q), which is a general index defined by the following equation:

$Q = I_{pav}*P_p+I_s*P_s$

where:
I_{pav} – Pavement Condition index
I_s – Safety index
P_p, P_s – weights for pavement condition and road safety, respectively. $P_p = 0.6$; $P_s = 0.4$.

It should be noted that the Pavement Condition Index (I_{pav}) is based on two roughness indicators available in the database, namely “Superficial Roughness Index” and “Evenness”. The Road Safety Index depends on “Flatland Safety Index” and “Highland Safety Index”. However, both indices are based on the proportion of network length in different condition categories and are not developed in a way that can be compatible with the approach used in COST 354 for developing combined and general performance indicators.

The “Quality Index” is defined on a scale of 0 to 100, and there are 6 condition categories. No further details are provided in the database.

Poland

Poland uses a General Index (GI) that is a function of several deterioration types and is defined by the following equation:

GI = 100-(Wn*Nj+Wr*Rj+Wk*Kj+Wsp*Spj+Ws*Sj)

where:

R_j - representative IRI (mm/m)
K_j – representative rut depth (mm)
S_{pj} – surface condition index
Sj – representative friction coefficient
N_j – cracking index
W_n, W_r, W_k, W_{sp}, W_s – corresponding weights

The index is used on motorways and other primary roads. No classes or index limits are provided in the database.

2.2 LITERATURE REVIEW

This section provides a literature review: for General Performance Indicators (GPI).

Approach 1

PIARC [1] recommends that a **General Performance Indicator** can be calculated as a weighted average of different Single Performance Indices or already Combined Performance Indices from different categories (i.e. structural and functional).

$$GPI = \frac{\sum_i PI_i \cdot W_i}{\sum_i W_i}$$

Where:
PI_i – is Performance Index (PI) number i
W_i - .is the weight assigned to PI number i.

This approach is also recommended in the scientific report for COST 354 STSM1 [2].

Approach 2

The second example is derived from work performed at Politechnica di Milano [3], where a Pavement Quality Index is calculated from longitudinal unevenness, friction and cracking:

$$IQS = \min\left\{30;30.38 - \left[(IRI \cdot 2.5) + 50 \cdot \left(\frac{6}{SFC_{60km/h}} - \frac{6}{65}\right) + (\%CRACKING \cdot 0.1)\right]\right\}$$

where:
IQS – Pavement Quality Index
IRI – Longitudinal Roughness Index
$SFC_{60km/h}$ – Side Force Coefficient
%CRACKING – percentage of cracked area of the pavement

This approach combines some of the Single Performance Indices into a GPI.

Approach 3

South Carolina DOT [4] is using a Pavement Quality Index (PQI). The PQI is a composite index computed using a Pavement Distress Index (PDI) and a Present Serviceability Index (PSI). The PDI is computed using a non-linear model and surface distress data obtained by keyboard/windshield surveys. For bituminous and composite pavements (bituminous over concrete), profiler-obtained rut depth data are also used in the computation of PDI. The PSI is computed using an exponential model and International Roughness Index (IRI) values derived from wheel path profiles obtained using non-contacting inertial profilers.

Approach 4

Minnesota DOT [5] is using a Pavement Quality Index (PQI) that is obtained from the following equation:

$$PQI = \sqrt{PSR \cdot SR}$$

where:

PSR – Present serviceability rating
Bituminous Pavements: $PSR = 5.697 - 2.104 \times IRI$
Concrete Pavements: $PSR = 6.634 - 2.812 \times IRI$
IRI = International Roughness Index, in m/km

SR – Surface Rating, given by the following equation:

$$SR = e^{1.386 - 0.045 \times TWD}$$

where:
TWD – Total weighted distress
Approach 5
In Japan, the Technical Standard for Pavement and Asset Management [6] suggests the following indices:

1) MCI (Maintenance Control Index) was developed in 1979

$$MCI = 10 - 1.48C^{0.3} - 0.29D^{0.7} - 0.47\sigma^{0.2}$$

where:
C - Cracking Ratio (%)
D - Rut Depth (mm)
σ - Evenness (mm)

2) Surface condition evaluation function (fs)

fs=10*MCI

3) Strcuture condition evaluation function (fb)

fb=100-b*(D/Ds-1)

where:
D - Deflection measured by the FWD
Ds - Standard value of deflection
b - parameter

4) HI (Health index)

HI=0.9fs+ 0.1fb

The rating in health evaluation is derived from the figure below:

Health Evaluation	Range of HI	Example of surface condition
I	70≤ HI ≤100	Wide range alligator cracking Heavy deep rutting
II	60≤ HI <70	Alligator cracking Deep rutting
III	40≤ HI <60	Dual line cracking Rutting
IV	20≤ HI <40	Single line cracking Small Rutting
V	0≤ HI <20	No cracking and rutting

Approach 6

The advanced maximum criteria described by Oertelt et al (see [7], [8]) is based on a breakdown rule where the index with the maximum value has the highest influence to the target general or combined index. To avoid that only one single value is the decisive factor, the input values of the others than the maximum value are taken into consideration. The percentage of the influence of these (other) indices will be selected subject to the field of application through the use of an influence factor. Oertelt combines exclusively two indices, where the percentage of influence for the second (minimum) value is between 10 and 20%.

This method can be extended to a combination of more than two indices. In doing so, the values of the indices other than the maximum value must be also combined initially. For this purpose different statistical representative values can be used (mean, median, maximum = second largest value, etc.).

2.3 CONCLUDING REMARKS

The information presented above shows that there are not many indices reported in the COST 354 database and in the literature reviewed that can be defined as global or general indicators. The most appropriate approach seems to be the definition of a GPI using a simple function to combine safety, comfort, structural adequacy and environment related CPIs.

However, the use of a simple linear function for calculation of a GPI from CPIs will not be enough; the selected function should be able to provide adequate information if the pavement is totally inadequate with respect to one of the combined indicators, even if the others have low values. The next section describes the combination procedure developed by COST 354 WP4 for the calculation of GPIs.

SECTION 3: DEVELOPMENT OF A GENERAL PERFORMANCE INDEX

This section concerns the development of a GPI for road pavements, using the following CPIs developed in the frame of COST 354 Work Package 3:

- Safety Index
- Comfort Index
- Structural Index
- Environmental Index.

As already referred in Work Packages 2 and 3 reports, it may be difficult to get appropriate input data for the calculation of a Combined Environmental Index. The Combination procedure developed and presented in this section can be used with or without a Combined Environmental Index. If PIs and CPIs for environmental issues are developed in the future, they easily can be introduced in the calculation of the GPI at any time.

3.1 SELECTION OF A FUNCTION

The procedure proposed for combination of CPI's into a GPI is based on the advanced maximum criteria. It takes into account the maximum weighted CPI value affected by biased values of other weighted CPIs. By using this method it is possible to combine different indices under different preconditions.

This method was selected in order to ensure that the final result of the GPI is strongly influenced by the maximum weighted CPI. For the practical application of the combination procedure two alternatives were developed. The alternatives give the user the possibility to consider the influence of the other weighted CPI's as follows:

- Alternative 1 considers the mean value of the weighted CPIs other than the maximum weighted CPI influenced by a factor *p*;
- Alternative 2 considers the second largest weighted CPI influenced by a factor *p*. All other weighted CPI's which are less than the second largest weighted CPI are not taken into consideration.

The influence factor *p* enables to control the total influence of the weighted CPIs in subject to their relevance. Based on investigations and analyses done in Germany the influence factor for the calculation of Combined Indices should be between 10 and 20% [7, 8] . A high *p* factor increases the influence of the other than the maximum weighted CPIs.

The reason for the application of the advanced maximum criteria can be given by the following example. If only the maximum value will be used for the combination procedure and no influence of the other weighted CPIs is given, then a section with safety in “poor” condition and comfort in “very good” condition will be similar to a section with safety and comfort in “poor” condition. There will be no difference in the value of the GPI.

In order to avoid this situation, the others than the maximum weighted CPI must be taken into consideration in the combination procedure. The two alternatives described above define the method of influence and the *p* factor defines the degree of influence. With regard to the given example a section with safety in "poor" condition and comfort in "very good" condition will not be similar to a section with safety and comfort in "poor" condition anymore. Subject to the weighting factor of the first index and the degree of influence of the second index, the section will be possibly in "very poor" condition from the GPI point of view.

The following equations show both alternatives for the calculation of a GPI:

<u>Alternative 1:</u>

$$GPI = \min\left[5; I_1 + \frac{p}{100} \cdot \overline{(I_2,...,I_n)}\right]$$

where

$$I_1 \geq I_2 \geq ... \geq I_n$$

and

$$I_1 = W_1 \cdot CPI_1, I_2 = W_2 \cdot CPI_2,..., I_n = W_n \cdot CPI_n .$$

<u>Alternative 2:</u>

$$GPI = \min\left[5; I_1 + \frac{p}{100} \cdot I_2\right]$$

where

$$I_1 \geq I_2 \geq ... \geq I_n$$

and

$$I_1 = W_1 \cdot CPI_1, I_2 = W_2 \cdot CPI_2,..., I_n = W_n \cdot CPI_n .$$

The weights represent the influence of the different CPIs on a relative basis. The CPI(s) with the highest weight should always have a weighting factor of 1.0. For example, if the maximum weight for the calculation of the General Performance Index is 0.8 for safety and no transformation took place, the value of the General Performance Index may be 4, although the Safety Index holds a value of 5.The correct answer of this example should hold a General Performance Index of 5 as well. Therefore it is necessary to guarantee, that the maximum weight in use is always equal to 1.0. In practice the weights of all used Combined Performance Indices will be transformed through the use of a linear transfer function if the maximum weight is less than 1.0.

Furthermore the transformation of the weights is not a section or area based commitment. It is a general commitment subject to the CPIs in use.

The following equations define the weight transformation when the maximum weighting factor is lower than 1.

$$W_1 = x.W_1'; W_2 = x.W_2'....W_n = x.W_n'$$

$$x = \frac{1}{\max\left[W_1', W_2'...W_n'\right]}$$

Figure 2 illustrates the influence of changing the weighting factors for one of the indices when using the advanced maximum criteria for combination of two indices.

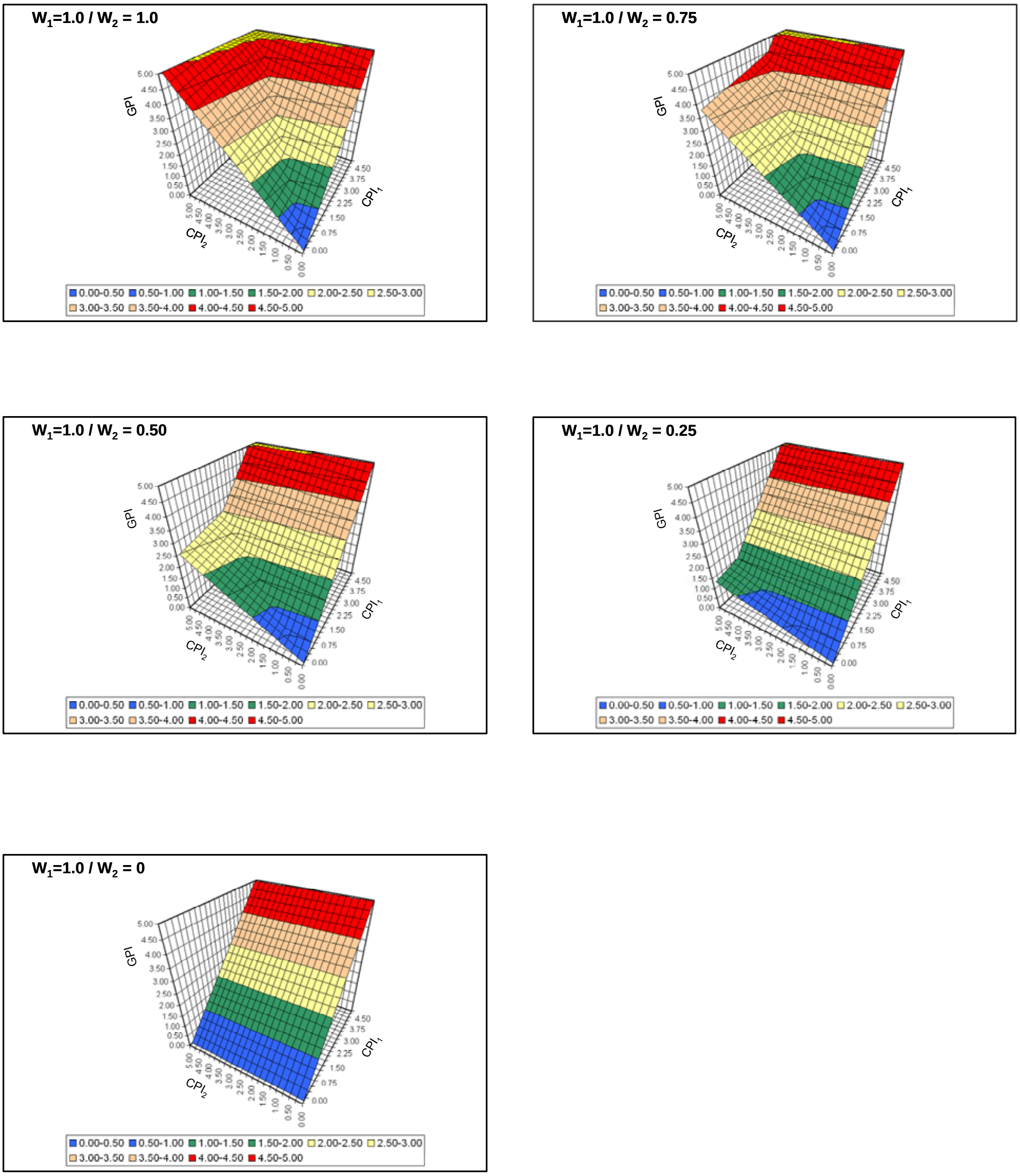

Figure 2 - Influence of weighting factors when using the advanced maximum criteria

3.2 WEIGHTING FACTORS FOR COMBINED INDICES

For the calculation of a GPI using the function presented in the previous section, it will be necessary to assign appropriate weighting factors to each of the CPIs adopted. Each user will be able to choose a set of weighting factors that reflect his / her priorities. These priorities may also be different for different types of networks.

In order to provide additional information for the choice of weighting factors, WP4 implemented a survey within the countries represented in COST 354. The purpose was to collect opinions from different groups of stakeholders concerning the relative importance of each type of Combined Performance Indicator. Each member of the Management Committee was asked to collect information among the following categories of respondents:

- Road Authorities;
- Road Operators
- Researchers
- Road Users.

Each respondent was asked to provide a relative importance factor (referred in the questionnaire which was distributed as “relative influence factor”) for each of the above combined pavement performance indices, taking into account the type of road network. In order to have a common scale, it was requested that the sum of relative importance factors for a given network type should be equal to 1. Figure 3 illustrates the questionnaire used for this purpose. Table A1 in the Appendix provides an overview of the replies gathered by COST 354 members:

The objective of COST 354 is the definition of uniform European performance indicators and indexes for road pavements. A Global Performance Index is an index that describes the overall performance of a road pavement, which can be used in optimisation procedures. The Global Performance Index for a given pavement will be calculated from 4 Combined Performance Indexes (PI) that describe the quality of the road pavement from different perspectives:

Road Safety PI	*A Performance Index that reflects the demands made on road pavements in order to provide safety to road users. This PI is only associated with the efect of the road pavement on safety, therefore it does not include other issues such as geometry.*
Riding Comfort PI	*A Performance Index that related to the demands made on road pavements in order to provide riding comfort to road users*
Pavement Structure PI	*A Performance Index that reflects the demands made on the road pavement structure in order to widthstand traffic loads*
Environment PI	*A Performance Index that reflects the demands on road pavements from na environment perspective*

Please provide a relative influence factor (from 0 to 1) for each of the above combined pavement performance indexes, taking into account the type of road network. The sum of influence factors for a given network type must be equal to 1.

Country					
Respondent *(choose one of the following oprions)*	**Name**				
	Road Administration				
	Road Operator				
	Road User				
	Researcher				
Type of network		**Motorways**	**Other Primary Roads**	**Secondary Roads**	**Other Roads**
Influence factor for Performance Indexes	**Road Safety**				
	Riding Comfort				
	Pavement Structure				
	Environment				
SUM		0	0	0	0

Figure 3 - Questionnaire on relative importance factors for CPIs

In total, the number of replies gathered within the COST 354 countries was the following:

- 22 replies from Road Administrators;
- 7 replies from Road Operators;
- 15 replies from Road Users (for example automobile clubs);
- 37 replies from Researchers.

The information gathered is presented in Appendix 1. Figure 4 shows the average relative importance factors per type of road and type of respondent.

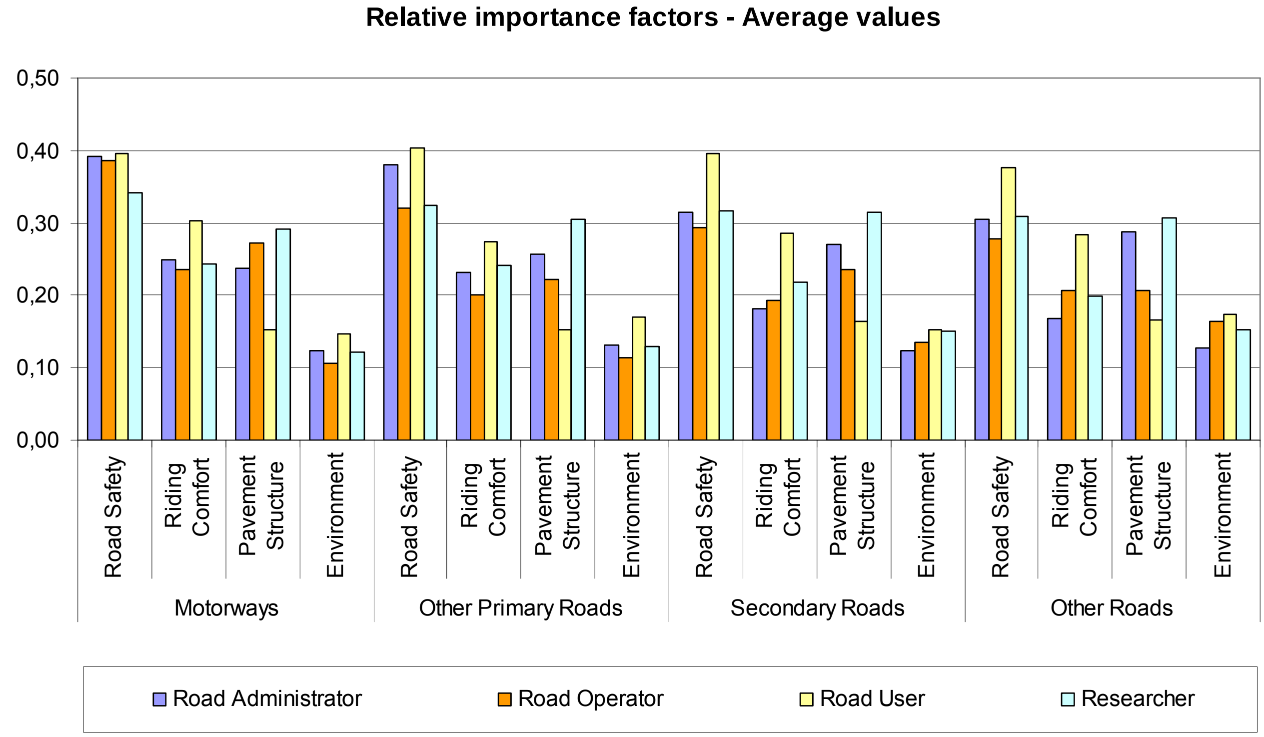

Figure 4 - Average replies per type of respondent and road category

In many cases it was difficult to differentiate whether a respondent to the questionnaire belonged to the group of “Road Administrators” or “Road Operators”, since very often a single organisation is in the two groups. Therefore, these two groups were merged into one group for subsequent analysis of the questionnaire, taking into consideration all answers together.

Fehler! Verweisquelle konnte nicht gefunden werden. to Figure 7 present the distribution of replies from Road Administrators and Operators, Road Users and Researchers, respectively. Table 1 to Table 3 provide the results of the analysis in detail subject to the road category and the representative statistical values.

Table 1 - Average, Median, Minimum and Maximum of relative importance factors assigned by Road Administrators and Operators

	Motorways				Other Primary Roads			
	Road Safety	Riding Comfort	Pavement Structure	Environment	Road Safety	Riding Comfort	Pavement Structure	Environment
Average	0.39	0.24	0.26	0.11	0.38	0.23	0.27	0.13
Median	0.40	0.23	0.20	0.10	0.40	0.20	0.30	0.10
Minimum	0.20	0.13	0.10	0.00	0.20	0.10	0.10	0.00
Maximum	0.50	0.40	0.50	0.20	0.50	0.40	0.50	0.30
	Secondary Roads				**Other Roads**			
	Road Safety	**Riding Comfort**	**Pavement Structure**	**Environment**	**Road Safety**	**Riding Comfort**	**Pavement Structure**	**Environment**
Average	0.35	0.21	0.31	0.14	0.34	0.20	0.30	0.16
Median	0.35	0.20	0.30	0.10	0.30	0.20	0.28	0.13
Minimum	0.15	0.10	0.10	0.00	0.10	0.10	0.10	0.05
Maximum	0.50	0.40	0.50	0.30	0.50	0.40	0.70	0.30

Road Administrator + Road Operator

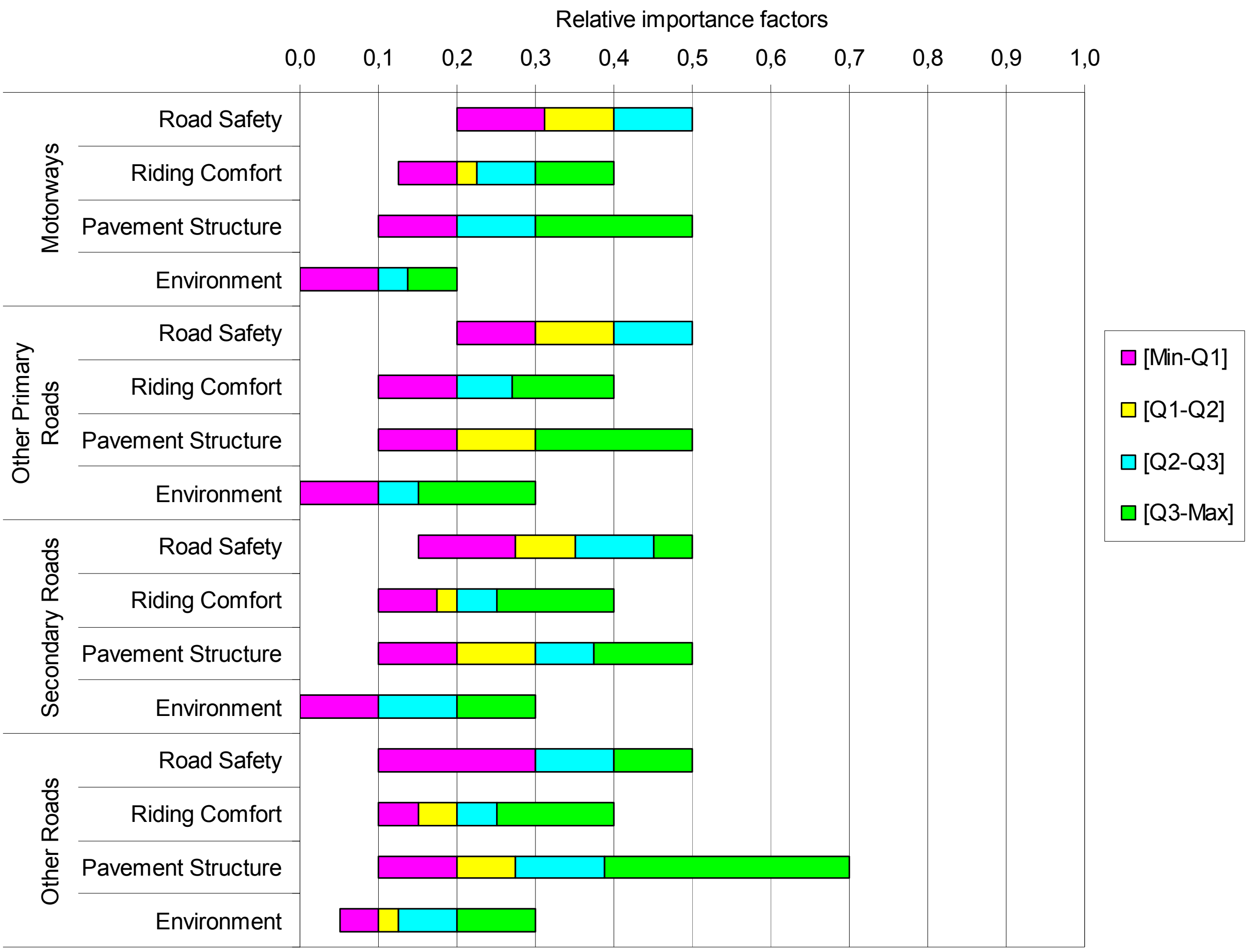

Figure 5 - Distribution of relative importance factors by quartiles - Road Administrators and Operators

Table 2 - Average, Median, Minimum and Maximum of relative importance factors assigned by Road Users

	Motorways				Other Primary Roads			
	Road Safety	Riding Comfort	Pavement Structure	Environment	Road Safety	Riding Comfort	Pavement Structure	Environment
Average	0.40	0.30	0.16	0.15	0.40	0.27	0.16	0.17
Median	0.40	0.25	0.20	0.15	0.40	0.25	0.20	0.15
Minimum	0.10	0.10	0.00	0.00	0.20	0.10	0.00	0.00
Maximum	0.75	0.50	0.30	0.30	0.70	0.50	0.30	0.35
	Secondary Roads				**Other Roads**			
	Road Safety	**Riding Comfort**	**Pavement Structure**	**Environment**	**Road Safety**	**Riding Comfort**	**Pavement Structure**	**Environment**
Average	0.40	0.29	0.16	0.15	0.38	0.28	0.17	0.17
Median	0.40	0.30	0.15	0.10	0.40	0.25	0.15	0.10
Minimum	0.15	0.00	0.00	0.00	0.10	0.00	0.00	0.00
Maximum	0.70	0.50	0.35	0.40	0.80	0.50	0.40	0.60

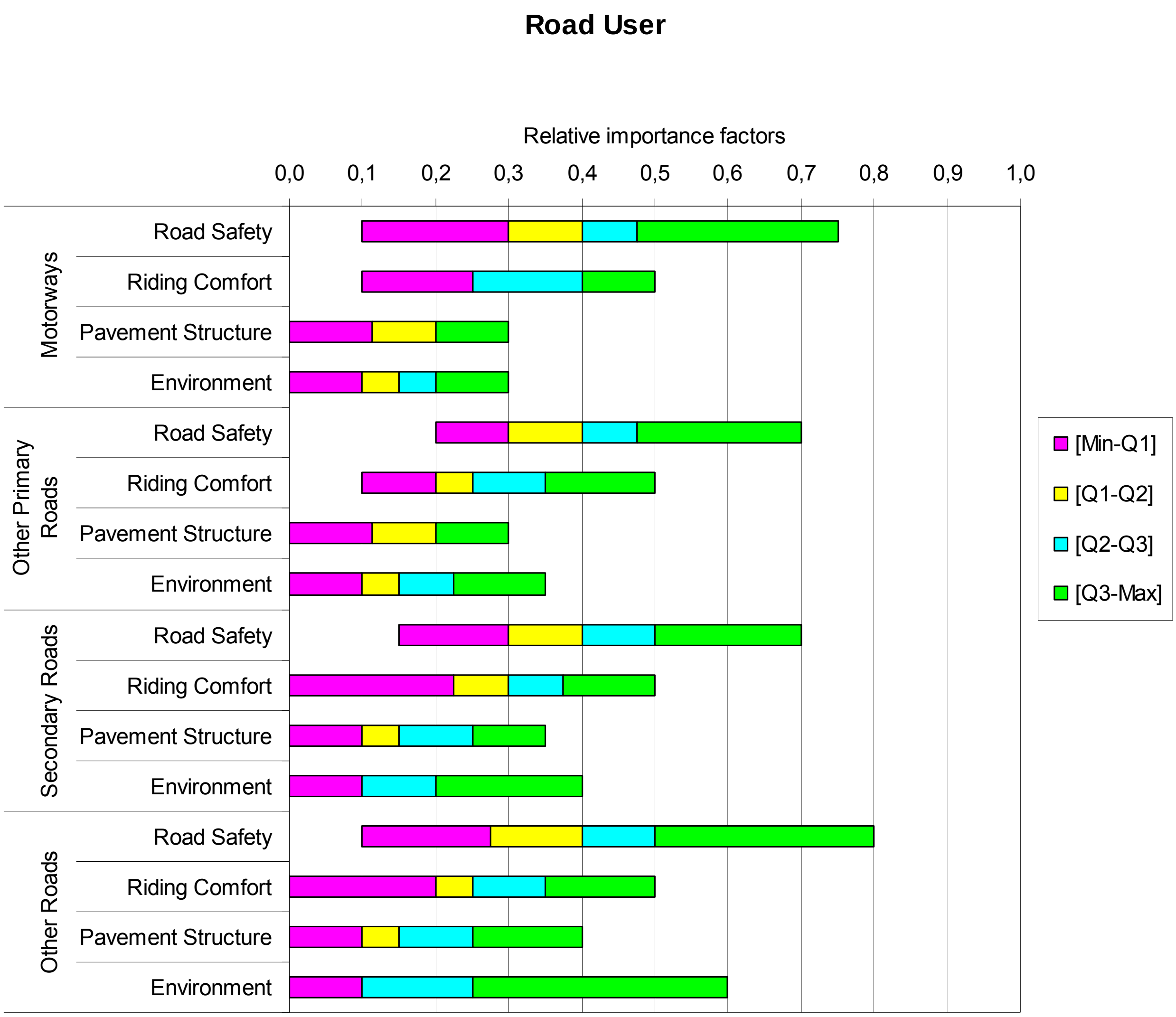

Figure 6 - Distribution of relative importance factors by quartiles - Road Users

Table 3 - Average, Median, Minimum and Maximum of relative importance factors assigned by Researchers

	Motorways				Other Primary Roads			
	Road Safety	Riding Comfort	Pavement Structure	Environment	Road Safety	Riding Comfort	Pavement Structure	Environment
Average	0.34	0.24	0.30	0.12	0.33	0.24	0.31	0.13
Median	0.35	0.25	0.30	0.10	0.35	0.25	0.30	0.10
Minimum	0.00	0.10	0.00	0.00	0.00	0.10	0.00	0.00
Maximum	0.50	0.50	0.75	0.25	0.50	0.50	0.75	0.20
	Secondary Roads				**Other Roads**			
	Road Safety	**Riding Comfort**	**Pavement Structure**	**Environment**	**Road Safety**	**Riding Comfort**	**Pavement Structure**	**Environment**
Average	0.32	0.22	0.32	0.15	0.32	0.20	0.32	0.16
Median	0.30	0.20	0.30	0.15	0.30	0.20	0.30	0.15
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	0.50	0.50	1.00	0.30	0.50	0.50	1.00	0.40

Figure 7 - Distribution of relative importance factors by quartiles - Road Users

In order to apply the advanced maximum criteria presented in Section 3.1, the weighing factors (W_1 to W_4) to be used in the combination procedure will be given in a different scale, where the highest value(s) must be equal to 1. For this purpose, the relative importance factors had to be transformed by a linear transfer function (see Section 3.1).

Despite of having received replies concerning the relative importance of CPI for "Other Roads", there was limited information in the database specific to Single or Combined Performance Indicators for this category of roads. Furthermore, the replies gathered in the questionnaire about relative importance factors were very similar for these two types of roads. Therefore, subsequent analysis was performed with a combination of elements collected for Secondary Roads and Other Roads.

Using the data gathered through the questionnaire and summarised in the previous Tables for the 3 groups of respondents as a background information, the weighting factors presented in **Fehler! Verweisquelle konnte nicht gefunden werden.** are suggested as default values.

Table 4 – Proposed weighting factors

Motorways			
Road Safety	Riding Comfort	Pavement Structure	Environment
1.00	0.70	0.65	0.25
Primary Roads			
Road Safety	Riding Comfort	Pavement Structure	Environment
1.00	0.70	0.80	0.30
Secondary and Other Roads			
Road Safety	Riding Comfort	Pavement Structure	Environment
1.00	0.65	1.00	0.35

The recommended weights in Table 4 are based on the statistical analysis of the answers given by a certain number of people all over Europe and in the USA. Before applying these weights in practice they should be checked for plausibility subject to the field of application, their objectives and other preconditions.

3.3 EXAMPLE FOR THE CALCULATION OF A GENERAL PERFORMANCE INDICATOR

Two examples on calculation of GPIs are presented in this section. The first one shows the calculation of a GPI when all four CPIs are available, while the second one presents calculation of a GPI in the case no Environmental CPI is available.

Case 1 – All four CPIs are available

For a motorway section the following values of CPIs were derived from single PIs:

- Road Safety Index RSI = 3.5
- Riding Comfort Index RCI = 3.0
- Structural Index SI = 4.0
- Environmental Index EI = 2.5

The values of individual CPIs and corresponding weighting factors are presented below

Table 5 – Overview of relevant information used for case 1

CPI Name	CPI_i	Weight, W_i	I_i=W_i CPI_i	Order
Road Safety	3.5	1.00	3.50	1
Riding Comfort	3.0	0.70	2.10	3
Structure	4.0	0.65	2.60	2
Environment	2.5	0.25	0.63	4

The value of the influence factor is p = 20 %.

Alternative 1

In the first alternative for calculation of the GPI, the average value for I_2 to I_4 is used:

$$\frac{I_2 + I_3 + I_4}{3} = \frac{2.60 + 2.10 + 0.63}{3} = 1.78$$

The GPI is:

$$GPI = \min\left[5; I_1 + \frac{p}{100} \cdot \overline{(I_2, I_3, ..., I_n)}\right] = \min\left[5; 3.5 + \frac{20}{100} \cdot 1.78\right] = 3.86$$

Alternative 2

In the second alternative only second highest' I value is used.

The GPI is:

$$GPI = \min\left[5; I_1 + \frac{p}{100} \cdot I_2\right] = \min\left[5; 3.5 + \frac{20}{100} \cdot 2.60\right] = 4.02$$

Case 2 – Environmental CPI is not available

In the second example, the same CPI values are analysed, except that environmental CPI is not available:

- Road Safety Index RSI = 3.5
- Riding Comfort Index RCI = 3.0
- Structural Index SI = 4.0

The values of individual CPIs and corresponding transformed weights are presented in the following table.

Table 6 – Overview of relevant information used for case 2

CPI Name	CPI_i	Weight W_i	I_i=W_i CPI_i	Order
Road Safety	3.5	1.00	3.50	1
Riding Comfort	3.0	0.70	2.10	3
Structure	4.0	0.65	2.60	2

The value of the influence factor is p = 20 %.

<u>Alternative 1</u>

In the first alternative for calculation of the GPI, the average value of I_2 and I_3 is used:

$$\frac{I_2 + I_3}{2} = \frac{2.60 + 2.10}{2} = 2.35$$

The GPIis:

$$GPI = \min\left[5; I_1 + \frac{p}{100} \cdot \overline{(I_2, I_3, ..., I_n)}\right] = \min\left[5; 3.5 + \frac{20}{100} \cdot 2.35\right] = 3.97$$

<u>Alternative 2</u>

The GPI calculated according to the second alternative remains the same as in the Case 1 example, since only the second highest value is used in the calculation of the GPI:

$$GPI = \min\left[5; I_1 + \frac{p}{100} \cdot I_2\right] = \min\left[5; 3.5 + \frac{20}{100} \cdot 2.60\right] = 4.02$$

SECTION 4: PROPOSAL FOR APPLICATION

4.1 PRACTICAL IMPLEMENTATION

A sensitivity analysis was performed using a spreadsheet tool, developed for the occasion. The tool itself allows for calculating CPIs from technical parameters (TPs) that the user derives from the various measurements or that he has collected in any other way. Based on these CPIs, a GPI is calculated. This spreadsheet is described in more detail in the WP3 report [9].

In general, the calculation can be done for three different road categories: motorways, primary roads and secondary roads. Upon the users needs, the calculation is done for single measured sections or for homogeneous sections. Basic road sections data is entered into four CPI spreadsheets named: “Comfort Index”, “Safety Index”, “Structural Index” and “Environment Index”.

For the calculation of a GPI the user can see the mean and median weighting factors gathered through the questionnaire presented in 3.2 for three groups of respondents. .Apart from these, a group of weighting factors, proposed by WP4 members, is shown. When deciding about weighting factors, one has to bear in mind, that, as suggested before, the highest value should always be equal to 1.

GPIs are calculated on the “General PI” spreadsheet. First, basic road sections information and calculated CPIs are collected. For road sections, the road category, the section start and end chainages are shown. For each of the CPIs considered, the weighted Single PIs, influence factors and calculated CPIs are shown.

The GPI is calculated using the advanced maximum criteria for combination of CPIs. For the combination procedure, the user should define her/his own CPI weighting factors. Like in the case of Single PIs, as guidance for the definition of weighting factors, the user can have a look at different sets of CPI weighting factors. From a drop-down list in the spreadsheet tool, the user can choose and look at the Administrator and Operator, User and Researcher sets of factors (mean and median). These factors were gathered through the questionnaire presented in 3.2, and can be found also on the “Weights CPIs” spreadsheet. This spreadsheet also contains the suggested factors (“Proposed”) presented in Table 4. An example can be seen in Figure 8 .

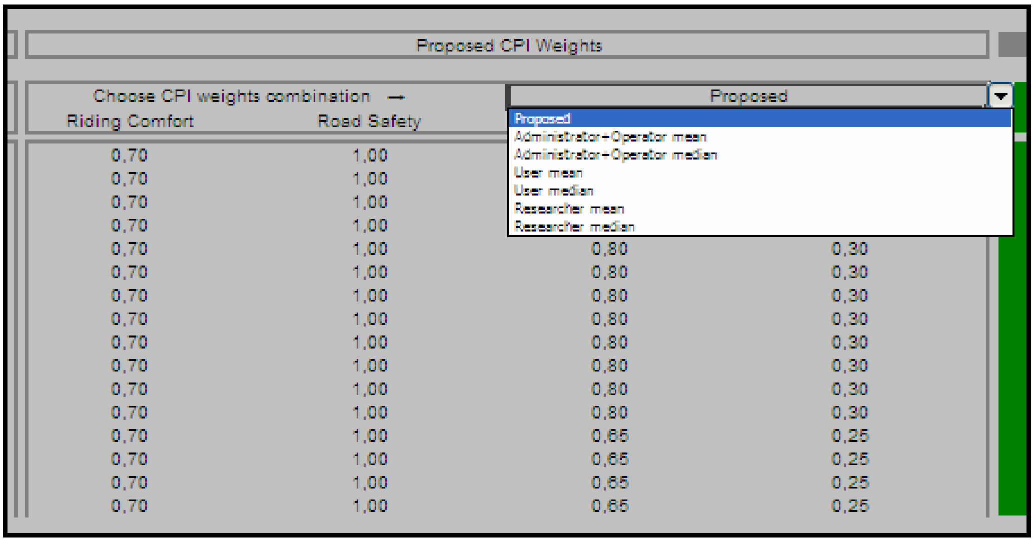

Figure 8 - Weighting factors for GPIs

4.2 SENSITIVITY ANALYSIS

After the spreadsheet tool was developed, it was used for performing a short sensitivity analysis. The idea was to gather together some data from real road sections, from different European countries, and use it for calculation of CPIs and GPIs. The sensitivity analysis was done by changing different parameters: firstly, the proposed sets of weighting factors both for Single PIs and for CPIs, and secondly, the influence factor p – thus increasing the influence of other than the maximal weighting factors towards the maximal one.

The data used for sensitivity analysis was gathered on actual pavement sections in Slovenia, Austria and UK, and it is described in WP3 report [9]. For performing the sensitivity analysis, data from Slovenia, Austria and UK were gathered. The data sets from Slovenia and Austria refer to homogeneous sections with different representative condition values, whereas the data sets from the UK refer to different data points in one specific section. The Single PIs were calculated using the own country's transformation functions. CPIs were then calculated for different options concerning the combination of Single PIs, as part of WP3 [9].

For testing the difference in calculated GPI values with different CPI weighting factors, seven sets of factors were taken into account. For each country the GPIs were calculated using "Administrators and Operators", "Users" and "Researchers" sets of average and median CPI weighting factors for the respective road categories. In addition to these six sets of factors, the calculation was done using the weighting factors suggested by WP4. For each set of factors, the influence factor p was varied between 0.1 and 0.5. The results for each of the three countries can be seen in Appendix 2 for all sets of weighting factors,

The results are presented with data points along the road using alternative 1 (see Section 3.1) in the calculation procedure. For calculating GPIs for each country, seven different sets of weighting factors were used. In the tool, these are presented in the "Weights CPIs" spreadsheet.

Figure 9 to Figure 11 illustrate the results obtained for the proposed weighting factors and for each country. From these figures, as well as from the results presented in Appendix 2, it can be seen that in general, where weighted CPIs level other than the highest one are low, changing of influence factor p has very limited impact, like in the UK case, which refers to data from one homogeneous section. When the level of weighted CPIs other than the highest one is high, like in the Austrian case, the influence factor has more impact on the GPI.

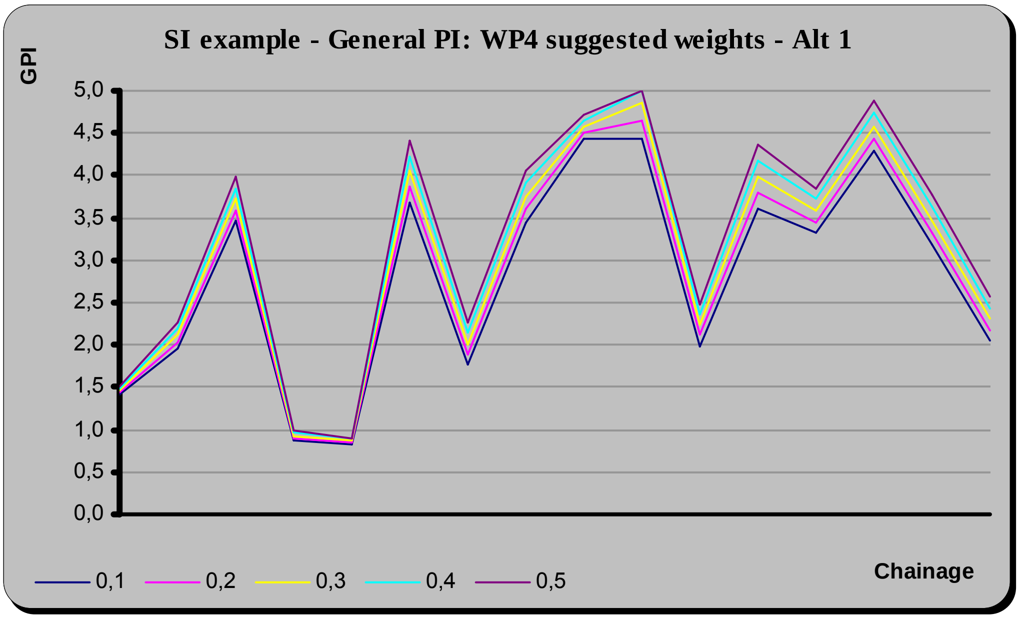

Figure 9 - Changes in General PIs due to changes in influence factor p, Slovenian case

Figure 10 - Change in General PIs due to change in influence factor p, Austrian case

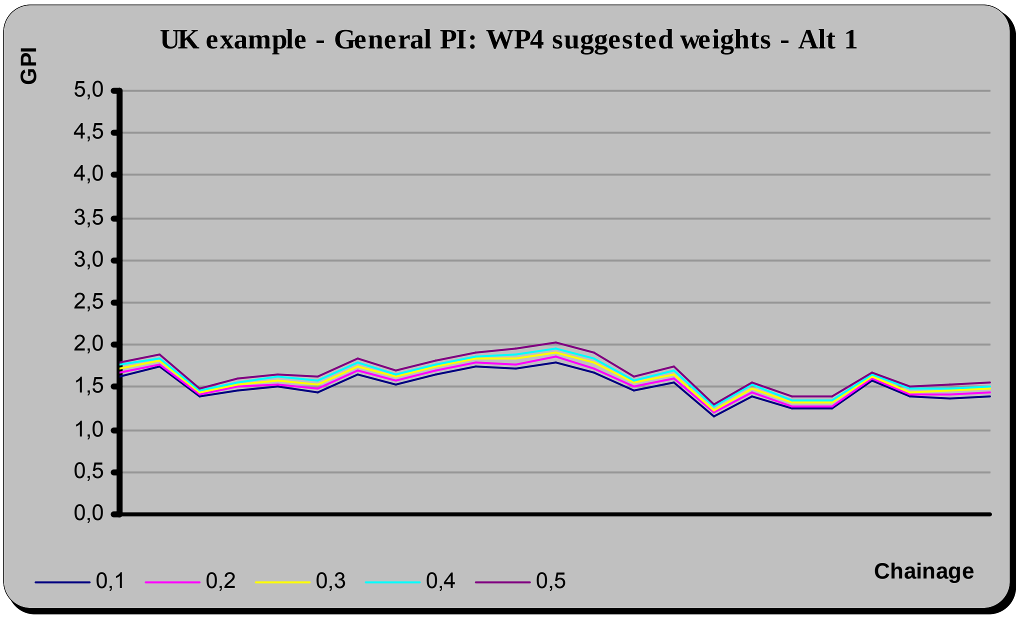

Figure 11 - Changes in General PIs due to change in influence factor p, UK case

Using the weighting factors proposed by WP4 and shown in Table 4, the two alternatives for application of the advanced maximum criteria were tested and the results compared. For each applied alternative, the influence factor p was varied between 0.1 and 0.5. The calculated GPIs for three countries can be seen from Figure 12 to Figure 14, where the results for alternative 1 (A1) and 2 (A2) are shown with thin and thick lines of the same colour, respectively. The results are presented with data points along the road.

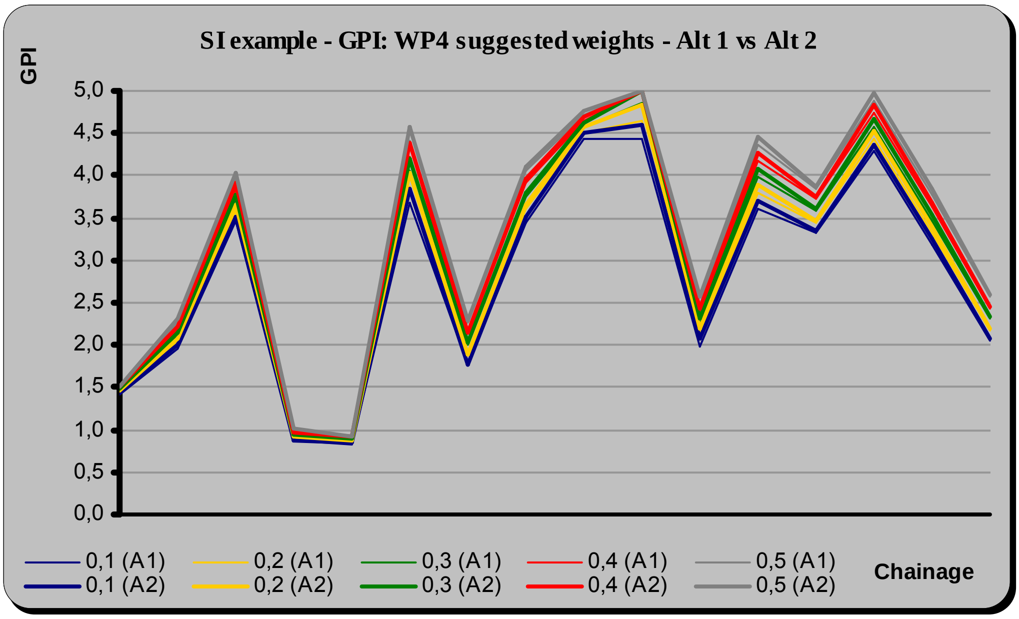

Figure 12 - General PIs calculated using alternatives 1 or 2 for advanced maximum criteria, Slovenian case

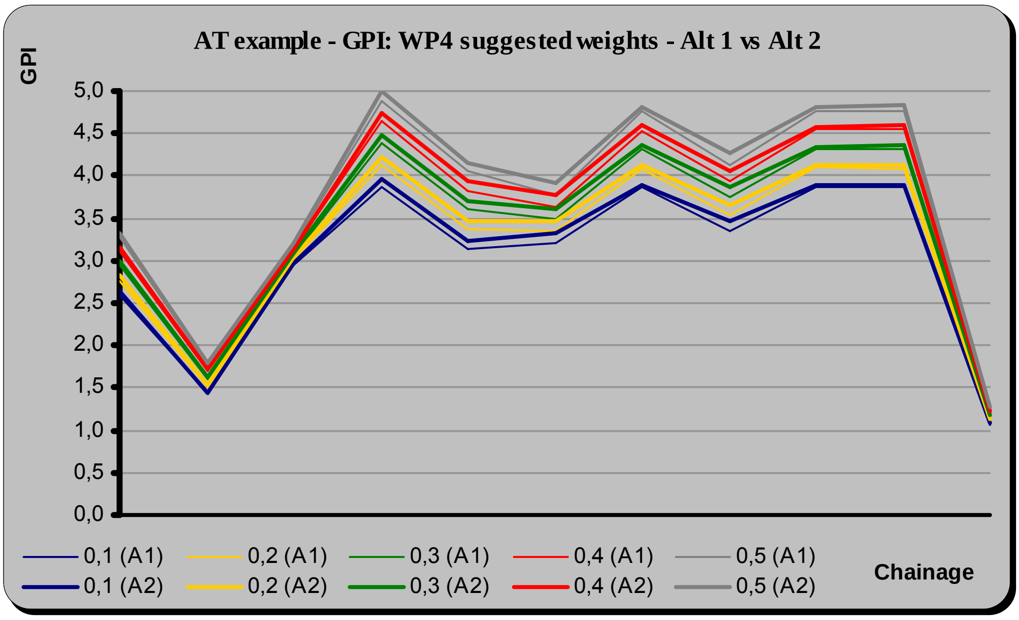

Figure 13 - General PIs calculated using alternatives 1 or 2 for advanced maximum criteria, Austrian case

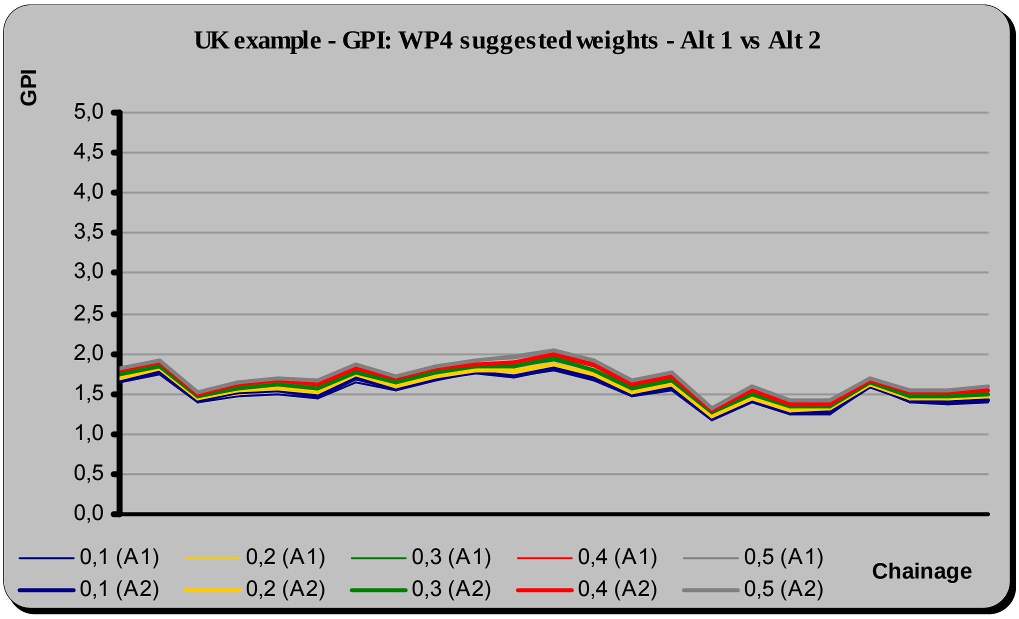

Figure 14 - General PIs calculated using alternatives 1 or 2 for advanced maximum criteria, UK case

It can be seen from figures that there the differences obtained with the two alternatives are higher for the Austrian case, where the level of some of the weighted Combined PIs other than the highest one, is significant. In the other two countries, the weighted CPIs other than the highest one are rather low, and therefore, the two different alternatives provide similar results.

Finally, a comparison was made between GPIs, calculated by using all seven sets of weighting factors, an influence factor of 0,1 and by applying alternatives 1 and 2. The results for all three countries are presented with data points along the road and shown in Figure 15 to Figure 17. In these figures, the results are identified as follows:

- WP4 – factors suggested by WP4 members;
- A+O – Administrators and Operators set of factors;
- U – Users set of factors;
- R – Researchers set of factors.

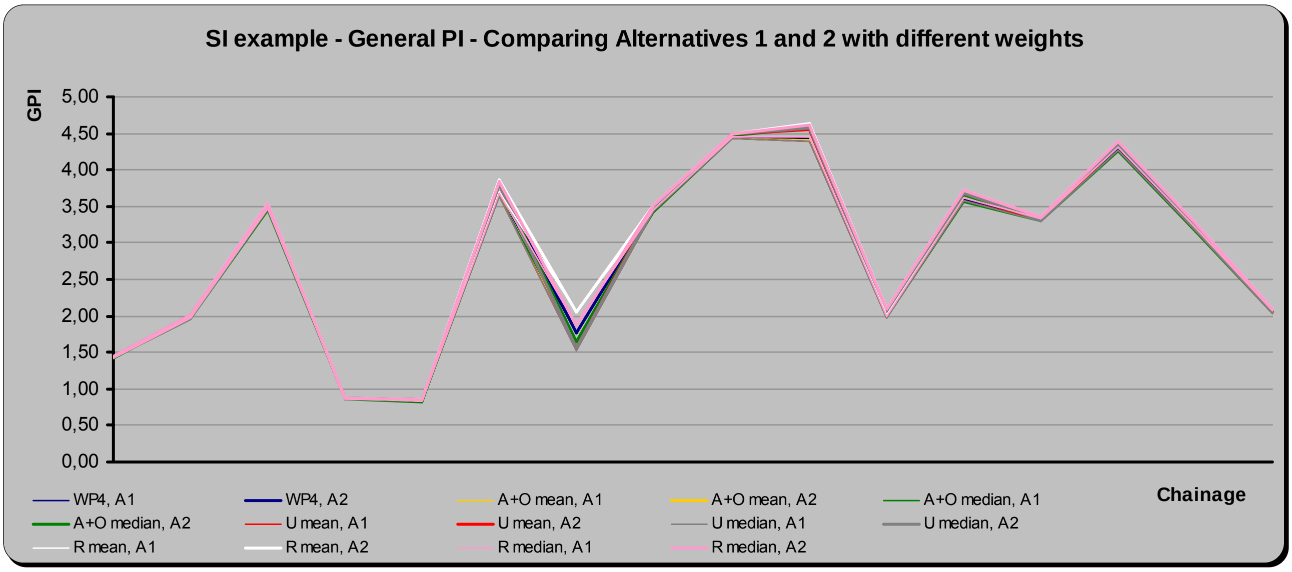

Figure 15 - General PIs calculated using alternatives 1 or 2 for advanced maximum criteria, and with all sets of weighting factors, Slovenian case

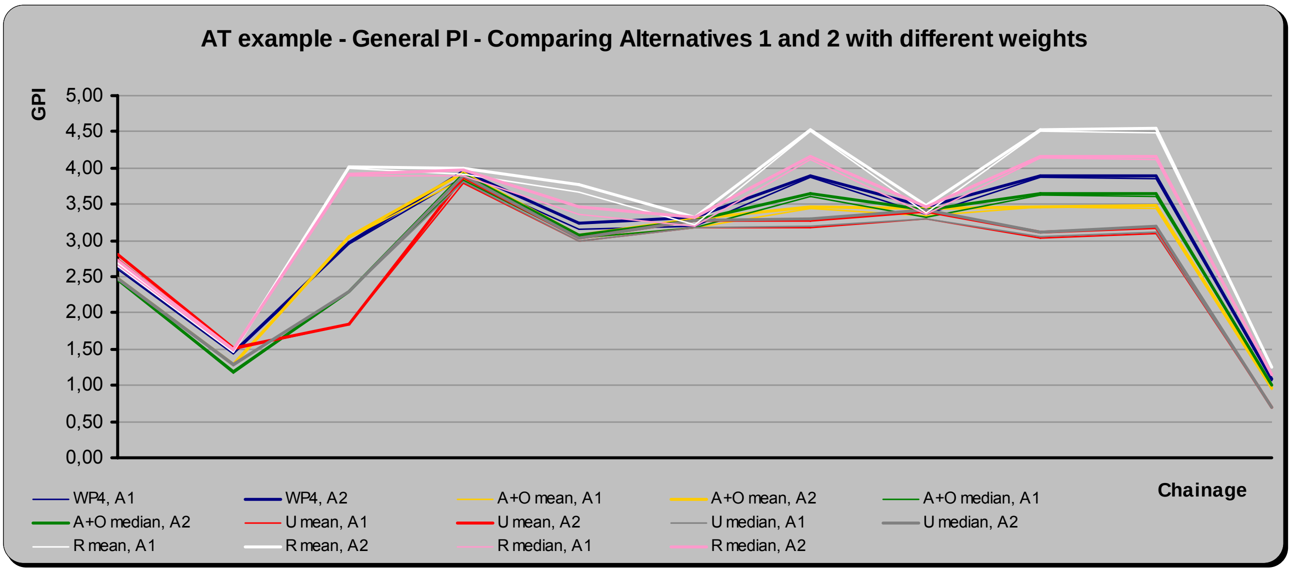

Figure 16 - General PIs calculated using alternatives 1 or 2 for advanced maximum criteria, and with all sets of weighting factors, Austrian case

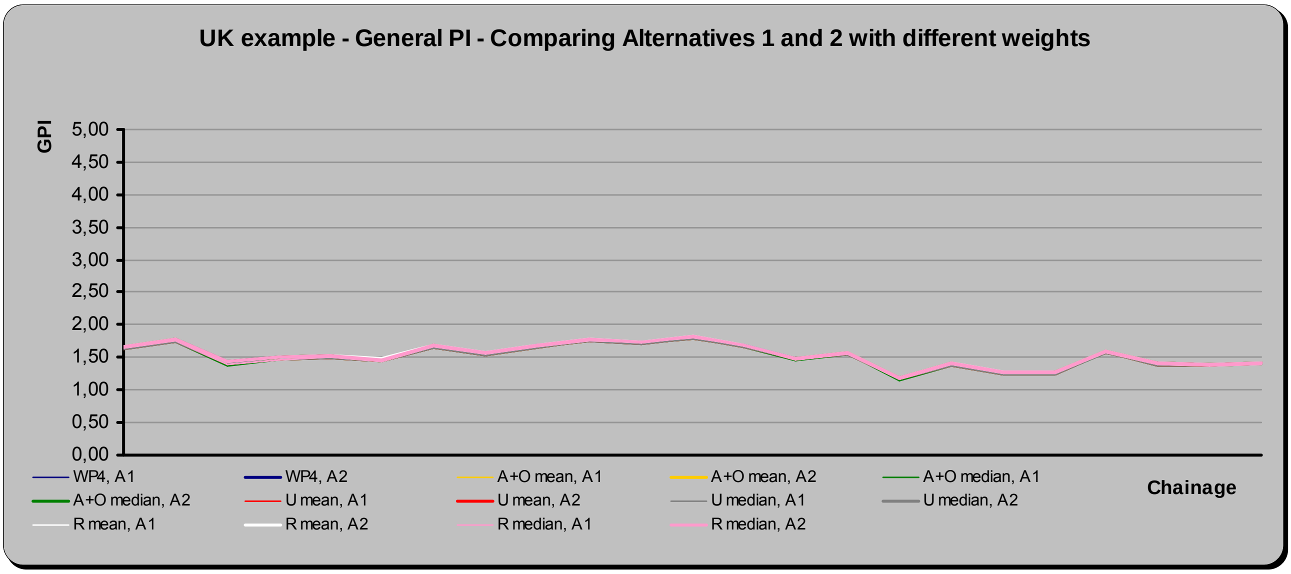

Figure 17 - General PIs calculated using alternatives 1 or 2 for advanced maximum criteria, and with all sets of weighting factors, UK case

As already pointed out, the results presented above show that, where weighted Combined PIs other than the highest one, are low, the impact of using different weighting factors or different alternatives is very limited.

When we compare results from the three sets of data, we can conclude that, when the different CPIs have higher values, the results become much more sensitive to the specific sets of weighting factors used, as well as to the choice of calculation alternatives or to the influence factor. This is the case for the Austrian data, where the rest of CPIs are relatively high compared to the highest one, and therefore, the variation in GPIs when the weighting factors or the influence factor change, is high.

In general, for a given value of the influence factor, p, alternative 1 will provide lower values of GPI than alternative 2. In practice, the use of alternative 2 means that only the first and second highest weighted CPIs are taken into account for the calculation of the GPI. On the other hand, when alternative 1 is used, all weighted CPIs are considered in the calculation, and their influence in the final result will depend on the selected value for the influence factor, p.

4.3 RECOMMENDATIONS FOR APPLICATION

The spreadsheet tool was meant to be a tool for performing a sensitivity analysis of proposed Combined PIs, and General PIs against practicality, adaptability and usefulness. It was prepared for testing of COST Action 354 Working Group 3 and 4 results for practical application based on real data coming from 3 different countries.

The spreadsheet can be used informatively for the calculation of General PI following the procedures developed within the work in COST Action. This should be done with great care, since the tool was tested only to a minor extent, and it might include some unintentional or misleading fault.

The tool was prepared in a way that practical application should be easy for the user, without having to define non-needed or duplicate information. For easier decisions, many options are given to the user in drop-down lists, including the proposed sets for weighting factors. When the CPIs and General PIs are calculated, it is done for technical parameters, derived from various measurements or collected by other forms of investigation, alongside the road sections. Calculations can be done for other road sections simply by copying the last row and pasting it to next ones, as many times as needed.

The recommended weights in Table 4 are based on the statistical analysis of the answers given by a certain number of people all over Europe. Before applying these weights in practice they should be checked for plausibility subject to the field of application, their objectives and other preconditions. To ensure that reliable results are achieved, the user should make a sensitivity analysis of her/ his own local performance data and define her/his own relative weighting factors.

SECTION 5: SUMMARY AND CONCLUSIONS

The objective of COST 354 Work Package 4 was to develop a procedure to bring together the Combined Performance Indices proposed by Work Package 3 into a General Performance Indicator. A general indicator gives a first impression of the overall pavement condition at network level, and points out weak sections. It is also used in optimisation procedures for maintenance management where only one specific target function can be optimised mathematically (maximized or minimized).

This General Performance Indicator developed within COST 354 must comprise all aspects of pavement performance, including safety, comfort, structural adequacy and environment. However, taking into account that during the course of the Action it was found that there is still limited information concerning environment indicators, the specific combination procedure for calculation of a General Performance Index should also be appropriate for use with only three Combined Performance Indices (CPI) (safety, comfort and structural indices).

The combination procedure recommended by COST 354 is based on the advanced maximum criteria. It takes into account the maximum weighted CPI value affected by biased values of other weighted CPIs. By using it is possible to ensure that the final result of the GPI is strongly influenced by the maximum weighted CPI. The weights (W_i) assigned to each Combined Performance Index are selected by the user and they may differ for each type of road network.

For the practical application of the combination procedure two alternatives were developed: alternative 1, which considers the mean value of the Combined Performance Indices (CPI_i) affected by a weighting factor (W_i) other than the maximum weighted CPI influenced by a factor *p* and; alternative 2 which considers the second largest weighted CPI influenced by a factor *p*. The equations for application of each alternative are the following:

<u>Alternative 1:</u>

$$GPI = \min\left[5; I_1 + \frac{p}{100} \cdot \overline{(I_2, ..., I_n)}\right]$$

where

$$I_1 \geq I_2 \geq ... \geq I_n$$

and

$$I_1 = W_1 \cdot CPI_1, I_2 = W_2 \cdot CPI_2, ..., I_n = W_n \cdot CPI_n .$$

<u>Alternative 2:</u>

$$GPI = \min\left[5; I_1 + \frac{p}{100} \cdot I_2\right]$$

where

$$I_1 \geq I_2 \geq ... \geq I_n$$

and

$$I_1 = W_1 \cdot CPI_1, I_2 = W_2 \cdot CPI_2, ..., I_n = W_n \cdot CPI_n .$$

In order to be able to make recommendations concerning the weighting factors to be assigned to each CPI, a short questionnaire was distributed among the Management Committee members, for collection of opinions of different stakeholders about the relative importance of each of theCPI for different types of road categories. The opinions were collected from Road Administrators, Road Operators, Road Users and Researchers. The road categories considered were Motorways, Primary Roads, Secondary Roads and Other Roads.

The replies from road Administrators and Road Operators were merged together, since it was difficult, in many cases, to differentiate whether an organization belonged to the first or to the second group. Also, the replies concerning Other Roads were combined with replies for Secondary Roads.

From the results obtained it could be seen that safety was generally the indicator with the highest relative importance, and environment was the one with the lowest. However, one has to bear in mind that the fact that there is limited information about environment related indicators, may have a negative effect on the ratings assigned to this indicator. Furthermore, within this Action, only road pavements are taken into account, and their specific influence on environment is limited, compared to the influence of traffic itself.

Using the results from the questionnaire as a background, a set of weighting factors are suggested for the implementation of the combination procedure developed by WP4, for Motorways, Primary Roads and Secondary and Other Roads. These weighting factors are presented in the table below.

Motorways			
Road Safety	Riding Comfort	Pavement Structure	Environment
1.00	0.70	0.65	0.25
Primary Roads			
Road Safety	Riding Comfort	Pavement Structure	Environment
1.00	0.70	0.80	0.30
Secondary and Other Roads			
Road Safety	Riding Comfort	Pavement Structure	Environment
1.00	0.65	1.00	0.35

In the frame of a Short Term Scientific Mission (STSM 5), a spreadsheet was developed for the calculation of Combined Performance Indices and a General Performance Index. A sensitivity analysis was performed using actual data from road pavements in Slovenia, Austria and UK. This analysis used the average and median weights for each group of respondent, as well as the weights recommended in the previous table and tested alternatives 1 and 2 for the calculation of the General Performance Index.

Relatively small differences were found when applying alternatives 1 and 2 for calculation of General PIs to data from Slovenia, and especially from the UK. In both cases, the other than the highest weighted PIs were relatively low. In the Austrian case, where both Single PIs and Combined PIs where high and relatively close to each other (also to the highest one), there is a larger variation in the General PI.

In practice, the use of alternative 2 means that only the first and second highest weighted CPIs are taken into account for the calculation of the GPI, whereas with alternative 1 all weighted CPIs are considered in the calculation, and their influence in the final result will depend on the selected value for the influence factor, p. For this reason, the use of alternative 1 is recommended for most applications.

Generally, where weighted Combined PIs level, except for the highest one, is low, changing of influence factor p has very limited effect, like it is in UK case. When the level of weighted Combined PIs with exception of the highest one, is high, the influence factor has more impact on the General PI.

It is recommended that, before applying in practice the proposed procedure for calculation of a General Performance Index, the user should check the weights assigned to each Combined Performance Indicator for plausibility, subject to the field of application, their objectives and other preconditions. To get reliable results, the user should make a sensitivity analysis of their own local performance data, using the spreadsheet developed by COST 354, and define his own weighting factors.

SECTION 6: GLOSSARY OF TERMS

Performance Indicator (PI)	A superior term of a technical road pavement characteristic (distress), that indicates the condition of it (e.g. transverse evenness, skid resistance, etc). It can be expressed in the form of a **technical parameter** (dimensional) and/or in the form of an **index** (dimensionless,)[cost 354]
Single Performance Indicator (SPI)	A dimensional or dimensionless number related with only one technical characteristic of the road pavement, indicating the condition of that characteristic (e.g. roughness) (also called Individual Performance Indicator)
Combined Performance Indicator (CPI)	A dimensional or dimensionless number related with two or more characteristics of the road pavement, that indicates the condition of all the characteristics involved (e.g. PCI-Pavement Condition Index)
General Performance Indicator (GPI)	A mathematical combination of single and/or combined indicators which describe the pavement condition concerning different aspects like safety, structure, riding comfort and environment (also called Global Performance Indicator).
Technical Parameter (TP)	A physic characteristic of the road pavement condition, derived from various measurements or collected by other forms of investigation (e.g. rut depth, friction value, etc).
Performance Index (PI)	An assessed technical parameter of the road pavement, **dimensionless** number or letter on a scale that evaluate the technical parameter involved (e.g. rutting index, skid resistance index, etc) in a 0 to 5 scale being 0 a very good condition and 5 a very poor one.

SECTION 7: REFERENCES

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APPENDIX 1 – QUESTIONNAIRE ON RELATIVE IMPORTANCE FACTORS

TABLE A 1 - Replies gathered by COST 354 members

Country	RA	RO	RU	RE
Austria			1	1
Belgium				1
Bulgaria		1	1	1
Croatia	1		1	
Czech Republic	2	1	1	1
Denmark	1			
Finland	1	1	1	5
France				
Germany	1			1
Greece		1	2	5
Hungary				1
Italy		1	1	
Netherlands	1			
Norway				
Poland				2
Portugal	2	1	1	1
Romania				2
Serbia and Montenegro	2		1	3
Slovenia	1		1	2
Spain				1
Sweden	5			1
Switzerland	1	1	1	1
U.K.	2			1
United States	2		3	7

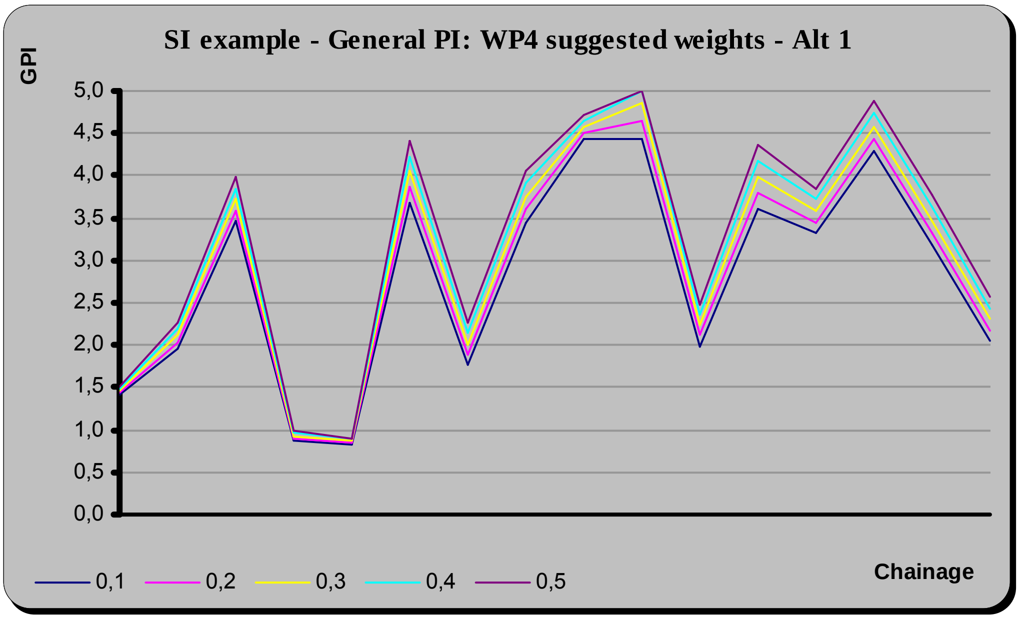
TABLE A 2 - Replies to the questionnaire (1/2)

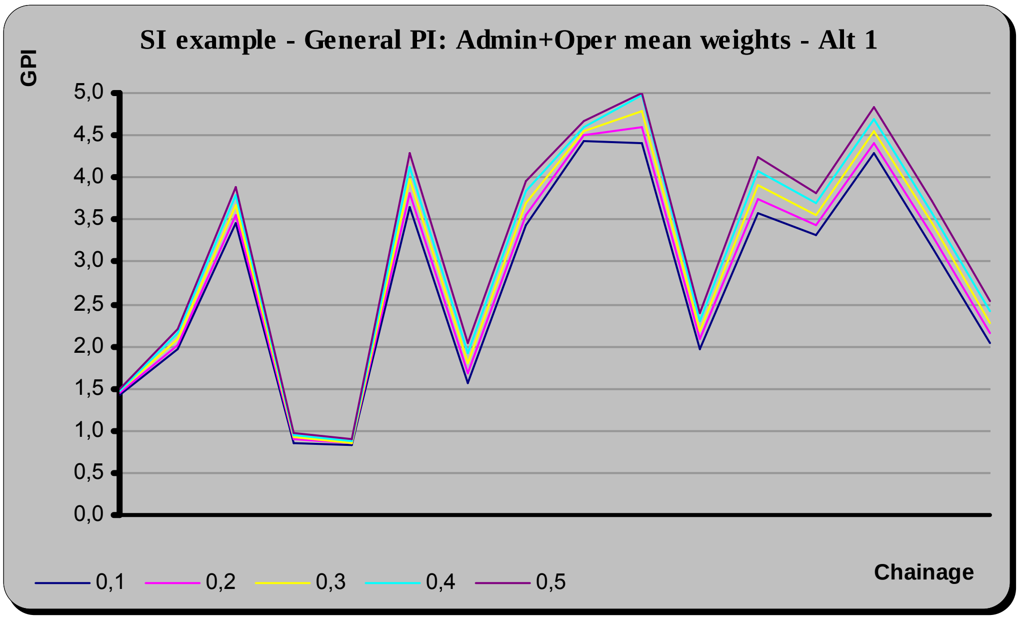
Country	Respondent	Motorways				Other Primary Roads				Secondary Roads				Other Roads			
	Type	Road Safety	Riding Comfort	Pavement Structure	Environment	Road Safety	Riding Comfort	Pavement Structure	Environment	Road Safety	Riding Comfort	Pavement Structure	Environment	Road Safety	Riding Comfort	Pavement Structure	Environment
Austria	Researcher	0.4	0.3	0.2	0.1	0.3	0.3	0.3	0.1	0.3	0.2	0.4	0.1	0.3	0.2	0.4	0.1
Austria	Road User	0.5	0.25	0.15	0.1	0.5	0.25	0.15	0.1	0.5	0.25	0.15	0.1	0.5	0.25	0.15	0.1
Belgium	Researcher	0.4	0.2	0.3	0.1	0.4	0.2	0.3	0.1	0.3	0.3	0.2	0.2				
Bulgaria	Researcher	0.4	0.3	0.2	0.1	0.4	0.25	0.25	0.1	0.4	0.2	0.3	0.1	0.4	0.2	0.3	0.1
Bulgaria	Road Operator	0.5	0.2	0.2	0.1	0.45	0.25	0.15	0.15	0.35	0.25	0.3	0.1	0.35	0.25	0.25	0.15
Bulgaria	Road User	0.3	0.25	0.25	0.2	0.25	0.25	0.25	0.25	0.15	0.35	0.35	0.15	0.1	0.5	0.3	0.1
Croatia	Road Administrator	0.4	0.2	0.3	0.1	0.35	0.25	0.3	0.1	0.3	0.2	0.4	0.1	0.3	0.2	0.4	0.1
Croatia	Road User	0.4	0.3	0.1	0.2	0.3	0.25	0.1	0.35	0.25	0.25	0.1	0.4	0.15	0.15	0.1	0.6
Czech Republic	Researcher	0.5	0.2	0.2	0.1	0.45	0.2	0.2	0.15	0.45	0.2	0.2	0.15	0.35	0.15	0.25	0.25
Czech Republic	Road Administrator	0.35	0.25	0.2	0.2	0.3	0.3	0.2	0.2	0.25	0.25	0.25	0.25	0.25	0.25	0.2	0.3
Czech Republic	Road Administrator	0.5	0.3	0.1	0.1	0.5	0.2	0.1	0.2	0.5	0.1	0.1	0.3	0.5	0.1	0.1	0.3
Czech Republic	Road Operator	0.5	0.15	0.3	0.05	0.5	0.15	0.3	0.05	0.5	0.1	0.35	0.05	0.4	0.2	0.2	0.2
Czech Republic	Road User	0.3	0.4	0.2	0.1	0.3	0.3	0.2	0.2	0.2	0.3	0.2	0.3	0.25	0.2	0.2	0.35
Denmark	Road Administrator	0.5	0.2	0.2	0.1	0.5	0.2	0.2	0.1								
Finland	Researcher	0.3	0.2	0.4	0.1	0.4	0.3	0.2	0.1	0.3	0.3	0.2	0.2	0.2	0.3	0.4	0.1
Finland	Road Administrator	0.3	0.35	0.2	0.15	0.3	0.35	0.2	0.15	0.3	0.3	0.3	0.1	0.3	0.3	0.3	0.1
Finland	Road Operator	0.2	0.4	0.3	0.1	0.2	0.4	0.3	0.1	0.2	0.4	0.3	0.1	0.2	0.4	0.3	0.1
Finland	Road User	0.35	0.5	0	0.15	0.35	0.5	0	0.15	0.5	0.5	0	0	0.5	0.5	0	0
Germany	Researcher/Road Admi	0.375	0.125	0.5	0	0.375	0.125	0.5	0	0.375	0.125	0.5	0				
Greece	Road Operator	0.5	0.2	0.2	0.1	0.5	0.2	0.1	0.2	0.4	0.2	0.1	0.3	0.4	0.2	0.1	0.3
Greece	Road User	0.2	0.5	0.2	0.1	0.2	0.5	0.2	0.1	0.3	0.5	0.1	0.1	0.3	0.5	0.1	0.1
Greece	Road User	0.6	0.1	0	0.3	0.6	0.1	0	0.3	0.6	0	0	0.4	0.6	0	0	0.4
Greece	Researcher	0.35	0.2	0.4	0.05	0.35	0.2	0.4	0.05	0.3	0.25	0.4	0.05	0.3	0.25	0.4	0.05
Greece	Researcher	0.4	0.3	0.2	0.1	0.3	0.3	0.3	0.1	0.3	0.3	0.2	0.2	0.3	0.2	0.2	0.3
Greece	Researcher	0.4	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.35	0.2	0.2	0.25	0.35	0.2	0.2	0.25
Greece	Researcher	0.3	0.2	0.3	0.2	0.3	0.2	0.3	0.2	0.3	0.3	0.2	0.2	0.3	0.3	0.2	0.2
Greece	Researcher	0.25	0.35	0.3	0.1	0.25	0.3	0.3	0.15	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Greece	Researcher	0.3	0.3	0.2	0.2	0.3	0.3	0.2	0.2	0.35	0.25	0.2	0.2	0.35	0.2	0.2	0.25
Hungary	Researcher	0.4	0.3	0.2	0.1	0.3	0.2	0.3	0.2	0.3	0.25	0.25	0.2	0.3	0.25	0.25	0.2
Italy	Road Operator	0.4	0.2	0.3	0.1	0.4	0.2	0.3	0.1	0.4	0.2	0.2	0.2	0.4	0.2	0.2	0.2
Italy	Road User	0.45	0.25	0.2	0.1	0.45	0.2	0.2	0.15	0.45	0.2	0.15	0.2	0.45	0.2	0.15	0.2
Netherlands	Road Administrator	0.4	0.2	0.3	0.1	0.4	0.2	0.3	0.1								
Poland	Researcher	0.25	0.25	0.25	0.25	0.3	0.25	0.25	0.2	0.35	0.2	0.25	0.2	0.35	0.2	0.25	0.2
Poland	Researcher	0.2	0.35	0.25	0.2	0.25	0.3	0.3	0.15	0.3	0.25	0.25	0.2	0.3	0.2	0.25	0.25
Portugal	Researcher	0.4	0.25	0.25	0.1	0.3	0.25	0.25	0.2	0.3	0.2	0.3	0.2	0.3	0.2	0.3	0.2
Portugal	Road Administrator	0.4	0.25	0.15	0.2	0.3	0.2	0.2	0.3	0.25	0.2	0.35	0.2	0.3	0.15	0.35	0.2

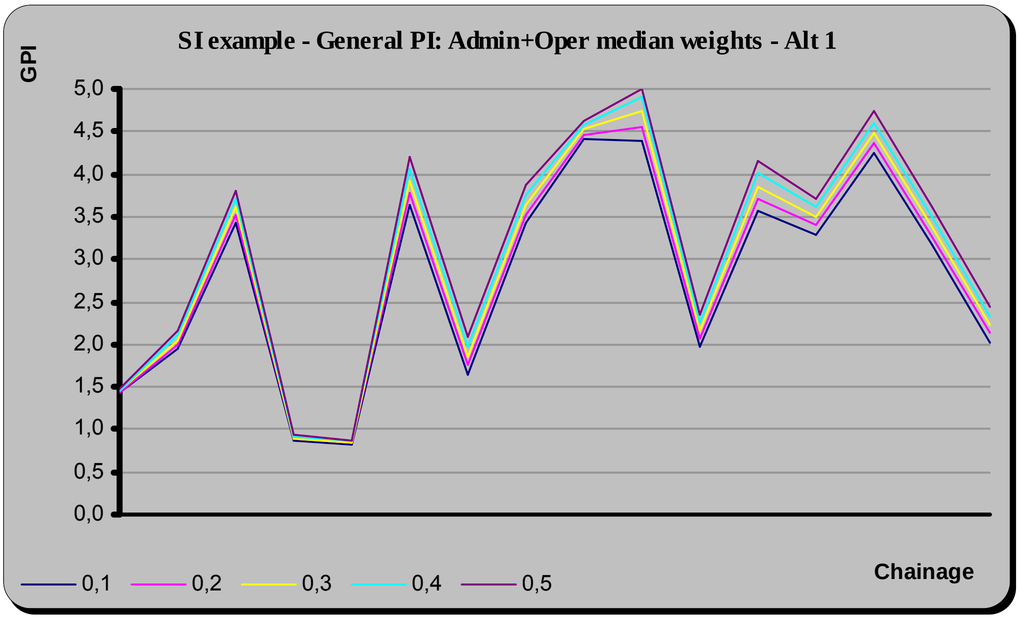
TABLE A 3 - Replies to the questionnaire (2/2)

Country	Respondent	Motorways				Other Primary Roads				Secondary Roads			
	Type	Road Safety	Riding Comfort	Pavement Structure	Environment	Road Safety	Riding Comfort	Pavement Structure	Environment	Road Safety	Riding Comfort	Pavement Structure	Environment
Portugal	Road Administrator	0.3	0.25	0.25	0.2	0.4	0.2	0.2	0.2	0.5	0.2	0.2	0.1
Portugal	Road Operator	0.4	0.3	0.2	0.1								
Portugal	Road User	0.4	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.4	0.2	0.3	0.1
Romania	Researcher	0.25	0.25	0.3	0.2	0.25	0.25	0.35	0.15	0.2	0.3	0.35	0.15
Serbia	Road User	0.1	0.5	0.3	0.1	0.5	0.2	0.2	0.1	0.4	0.1	0.3	0.2
Serbia	Researcher	0.35	0.2	0.3	0.15	0.3	0.25	0.25	0.2	0.3	0.2	0.3	0.2
Serbia	Researcher	0.35	0.25	0.3	0.1	0.35	0.25	0.3	0.1	0.3	0.2	0.4	0.1
Serbia	Road Administrator	0.3	0.25	0.35	0.1	0.3	0.25	0.35	0.1	0.3	0.25	0.35	0.1
Serbia	Road Administrator	0.35	0.3	0.25	0.1	0.3	0.3	0.3	0.1	0.3	0.25	0.3	0.15
Serbia	Researcher	0.4	0.2	0.3	0.1	0.4	0.1	0.4	0.1	0.3	0.1	0.5	0.1
Slovenia	Researcher	0.3	0.2	0.3	0.2	0.3	0.2	0.3	0.2	0.5	0.1	0.3	0.1
Slovenia	Researcher	0.35	0.3	0.25	0.1	0.35	0.25	0.25	0.15	0.35	0.2	0.3	0.15
Slovenia	Road Administrator	0.5	0.2	0.2	0.1	0.5	0.1	0.3	0.1	0.5	0.1	0.3	0.1
Slovenia	Road User	0.3	0.4	0.1	0.3	0.3	0.4	0.1	0.3	0.5	0.3	0.1	0.1
Spain	Researcher	0.4	0.25	0.3	0.05	0.4	0.25	0.3	0.05	0.4	0.25	0.25	0.1
Sweden	Researcher	0.35	0.1	0.5	0.05	0.35	0.1	0.5	0.05	0.2	0.1	0.65	0.05
Sweden	Road Administrator	0.4	0.3	0.2	0.1	0.5	0.25	0.2	0.05	0.4	0.2	0.35	0.05
Sweden	Road Administrator	0.4	0.3	0.2	0.1	0.3	0.3	0.3	0.1	0.2	0.2	0.5	0.1
Switzerland	Researcher	0.4	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.4	0.2	0.2	0.2
Switzerland	Road Administrator	0.5	0.15	0.2	0.15	0.5	0.15	0.2	0.15	0.5	0.15	0.2	0.15
Switzerland	Road Operator	0.2	0.2	0.4	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.4	0.2
Switzerland	Road User	0.4	0.25	0.2	0.15	0.4	0.25	0.2	0.15	0.4	0.25	0.2	0.15
UK	Researcher	0.35	0.25	0.3	0.1	0.35	0.25	0.3	0.1	0.35	0.25	0.3	0.1
UK	Road Administrator	0.4	0.3	0.2	0.1	0.4	0.3	0.2	0.1	0.4	0.3	0.2	0.1
UK	Road Administrator	0.5	0.27	0.17	0.06	0.5	0.27	0.17	0.06	0.5	0.27	0.17	0.06
United States	Researcher	0.2	0.2	0.4	0.2	0.1	0.3	0.4	0.2	0.1	0.2	0.4	0.3
United States	Researcher	0	0.25	0.75	0	0	0.25	0.75	0	0	0	1	0
United States	Researcher	0.5	0.5	0	0	0.5	0.5	0	0	0.5	0.5	0	0
United States	Researcher	0.3	0.3	0.3	0.1	0.2	0.3	0.4	0.1	0.2	0.3	0.4	0.1
United States	Researcher	0.5	0.15	0.3	0.05	0.5	0.15	0.3	0.05	0.5	0.1	0.3	0.1
United States	Researcher	0.4	0.1	0.4	0.1	0.35	0.15	0.4	0.1	0.4	0.15	0.3	0.15
United States	Researcher	0.3	0.2	0.3	0.2	0.3	0.2	0.3	0.2	0.3	0.2	0.3	0.2
United States	Road Administrator	0.3	0.2	0.4	0.1	0.3	0.2	0.4	0.1	0.3	0.2	0.4	0.1
United States	Road Administrator	0.25	0.2	0.4	0.15	0.2	0.15	0.5	0.15	0.15	0.1	0.5	0.25
United States	Road User	0.4	0.1	0.3	0.2	0.4	0.1	0.3	0.2	0.3	0.4	0.2	0.1
United States	Road User	0.5	0.3	0.2	0	0.4	0.4	0.2	0	0.3	0.4	0.3	0
United States	Road User	0.75	0.25	0	0	0.7	0.2	0.1	0	0.7	0.3	0	0

APPENDIX 2 – SENSITIVITY ANALYSIS






SI example - General PI: Admin+Oper median weights - Alt 1
GPI
5,0
4,5
4,0
3,5
3,0
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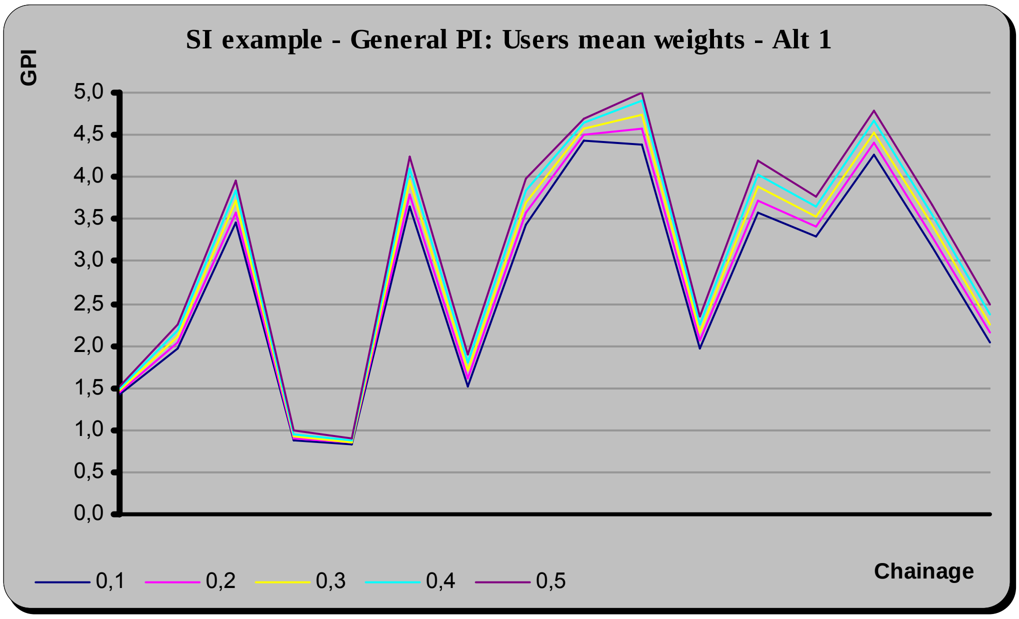
1,5
1,0
0,5
0,0
Chainage
0,1
0,2
0,3
0,4
0,5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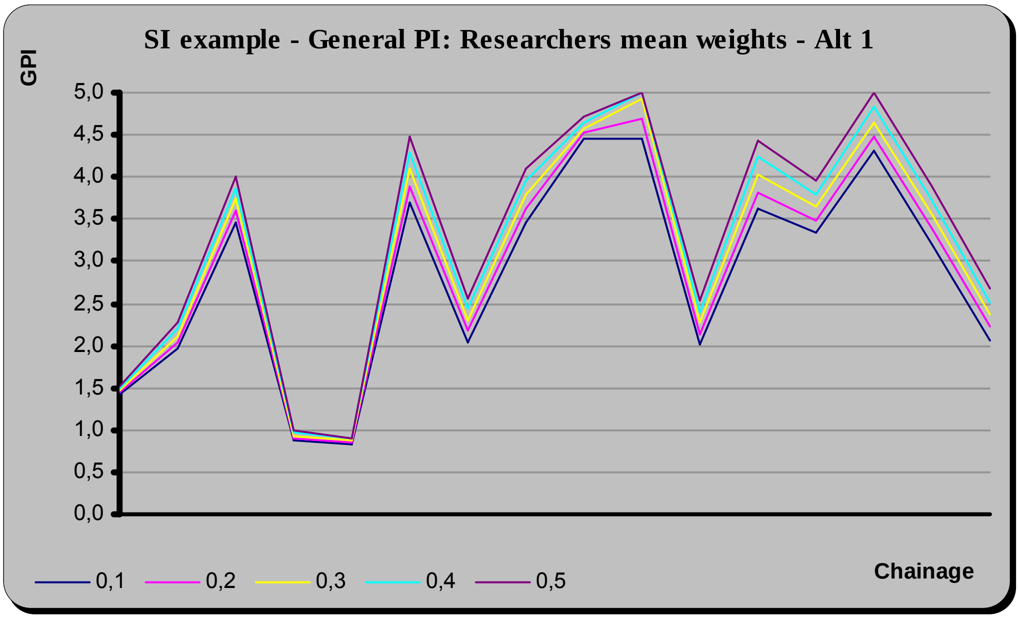
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Chainage
0,1
0,2
0,3
0,4
0,5


SI example - General PI: Users median weights - Alt 1
GPI
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Chainage
0,1
0,2
0,3
0,4
0,5


SI example - General PI: Researchers mean weights - Alt 1
GPI
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4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Chainage
0,1
0,2
0,3
0,4
0,5


SI example - General PI: Researchers median weights - Alt 1
GPI
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0,1
0,2
0,3
0,4
0,5
Chainage


AT example - General PI: WP4 suggested weights - Alt 1
GPI
5,0
4,5
4,0
3,5
3,0
2,5
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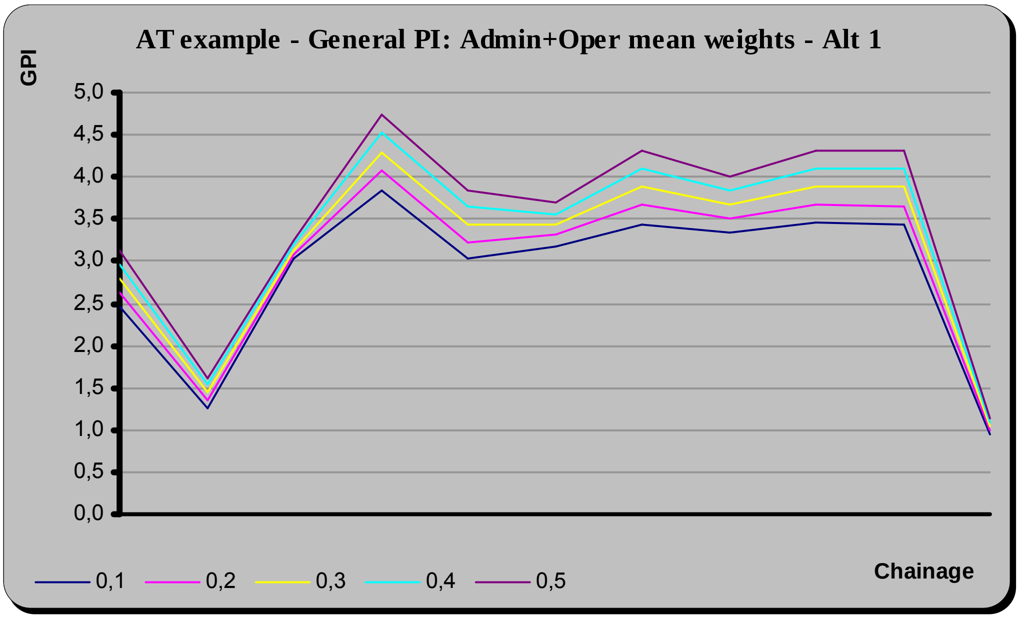
1,5
1,0
0,5
0,0
0,1
0,2
0,3
0,4
0,5
Chainage


AT example - General PI: Admin+Oper mean weights - Alt 1
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0,0
0,1
0,2
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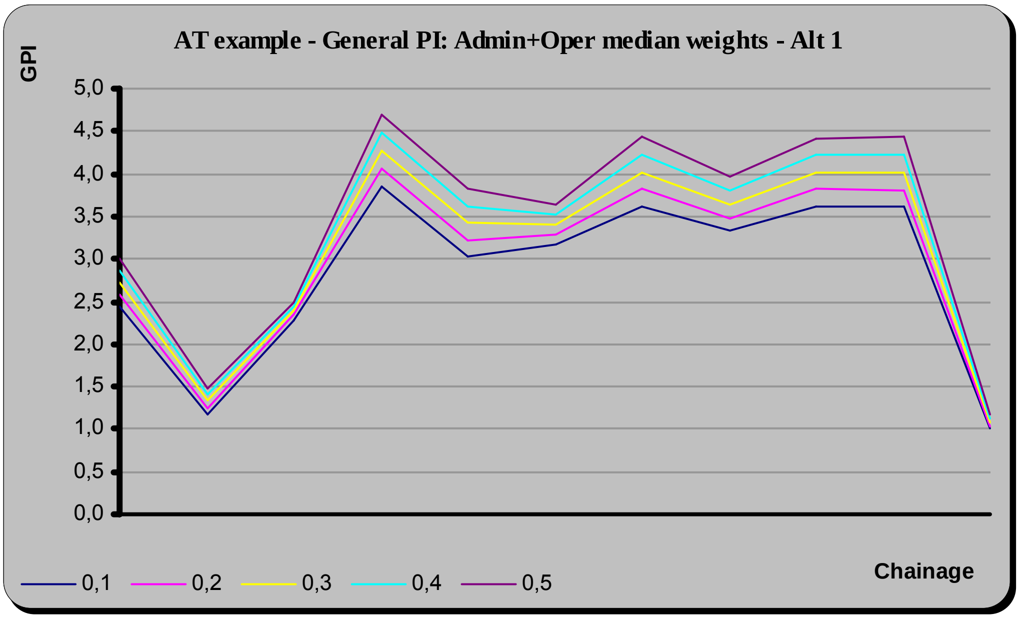
0,4
0,5
Chainage


AT example - General PI: Admin+Oper median weights - Alt 1
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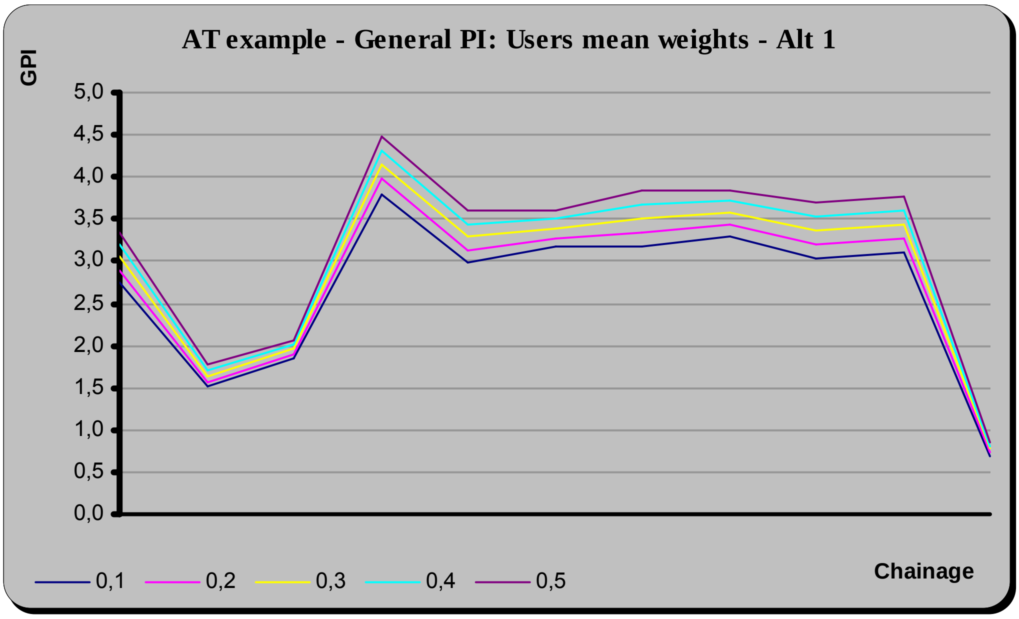
0,5
0,0
0,1
0,2
0,3
0,4
0,5
Chainage


AT example - General PI: Users mean weights - Alt 1
GPI
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4,5
4,0
3,5
3,0
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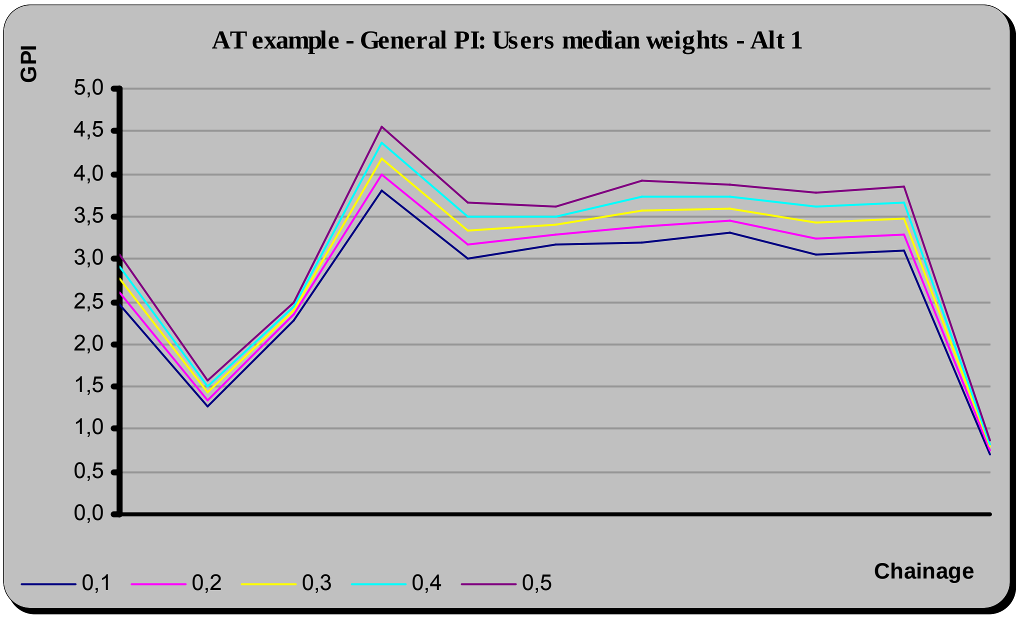
2,0
1,5
1,0
0,5
0,0
Chainage
0,1
0,2
0,3
0,4
0,5


AT example - General PI: Users median weights - Alt 1
GPI
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4,5
4,0
3,5
3,0
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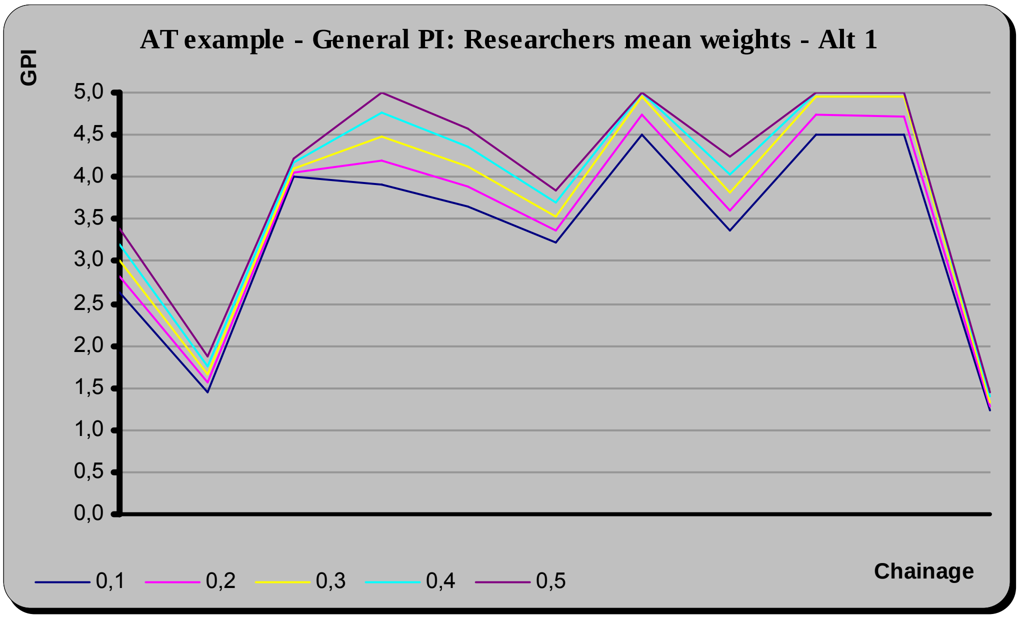
1,5
1,0
0,5
0,0
Chainage
0,1
0,2
0,3
0,4
0,5


AT example - General PI: Researchers mean weights - Alt 1
GPI
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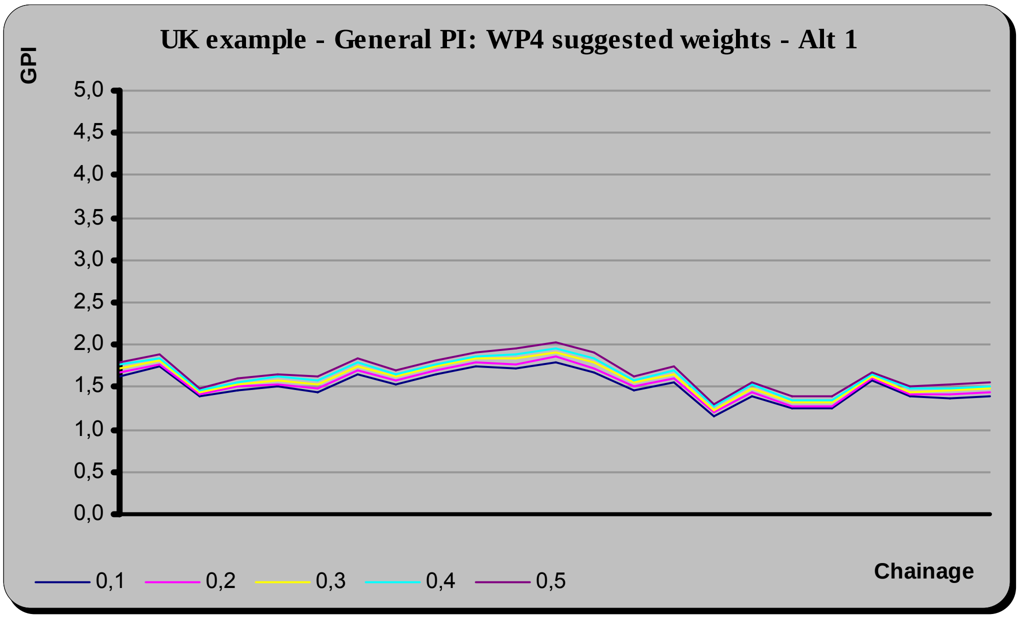
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Chainage
0,1
0,2
0,3
0,4
0,5


AT example - General PI: Researchers median weights - Alt 1
GPI
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Chainage
0,1
0,2
0,3
0,4
0,5


UK example - General PI: WP4 suggested weights - Alt 1
GPI
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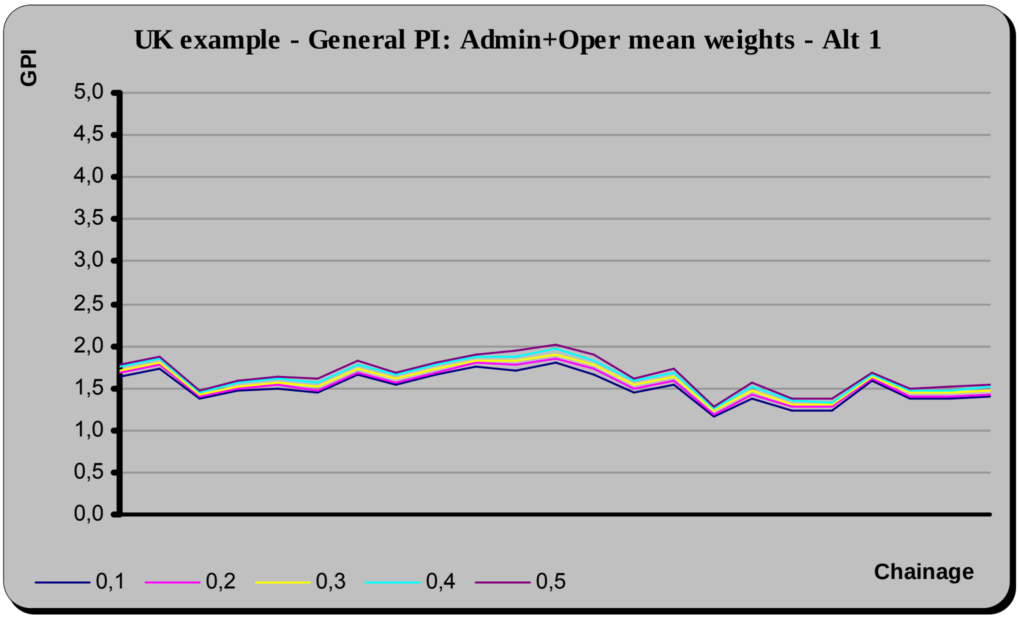
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0,1
0,2
0,3
0,4
0,5
Chainage


UK example - General PI: Admin+Oper mean weights - Alt 1
GPI
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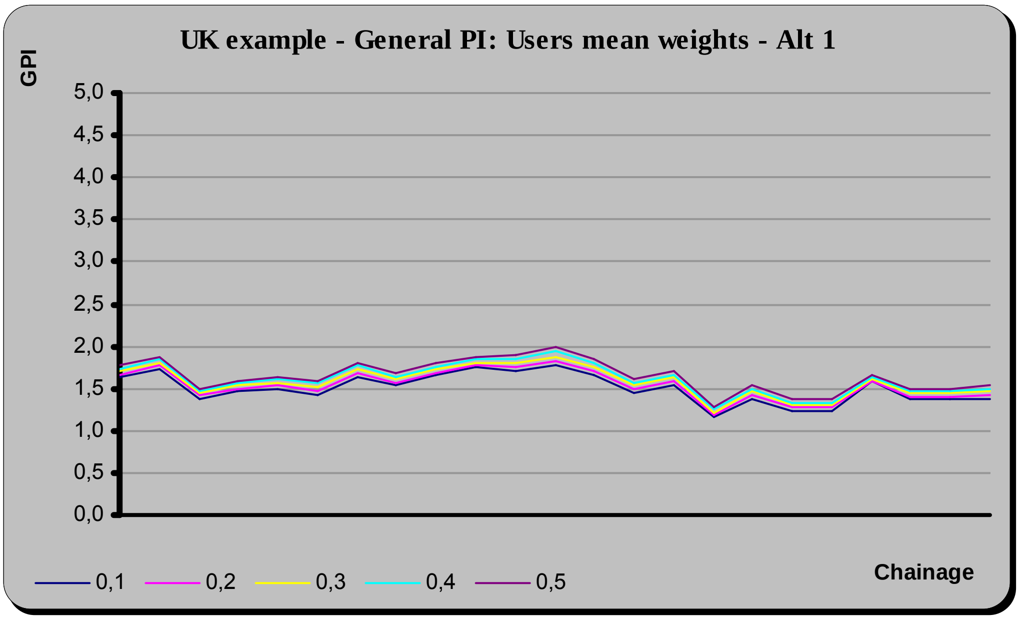
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0,1
0,2
0,3
0,4
0,5
Chainage


UK example - General PI: Admin+Oper median weights - Alt 1
GPI
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
0,1
0,2
0,3
0,4
0,5
Chainage


UK example - General PI: Users mean weights - Alt 1
GPI
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4,5
4,0
3,5
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1,5
1,0
0,5
0,0
0,1
0,2
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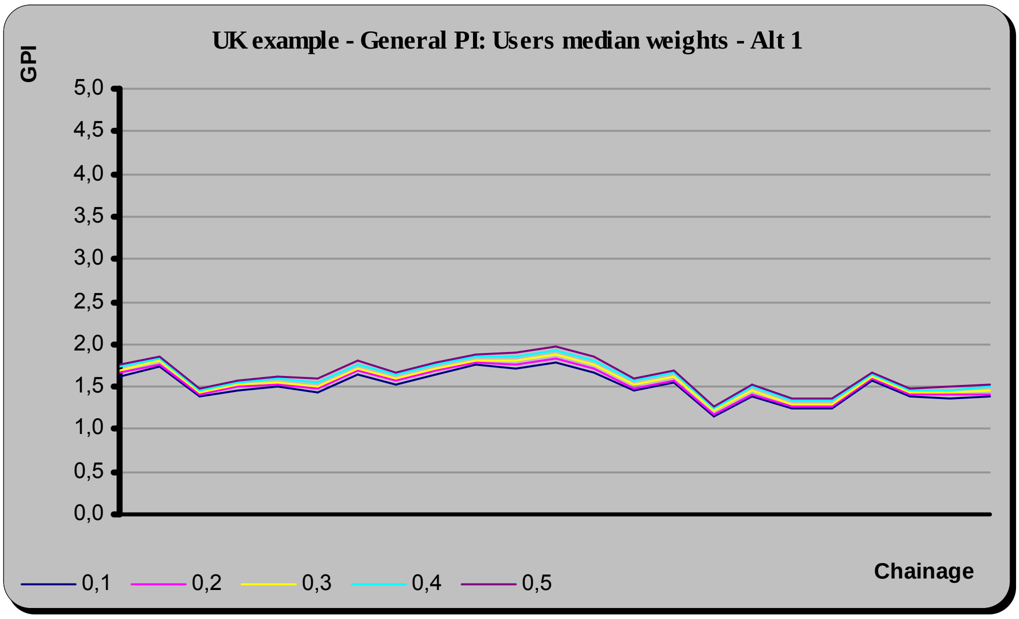
0,4
0,5
Chainage


UK example - General PI: Users median weights - Alt 1
GPI
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3,5
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Chainage
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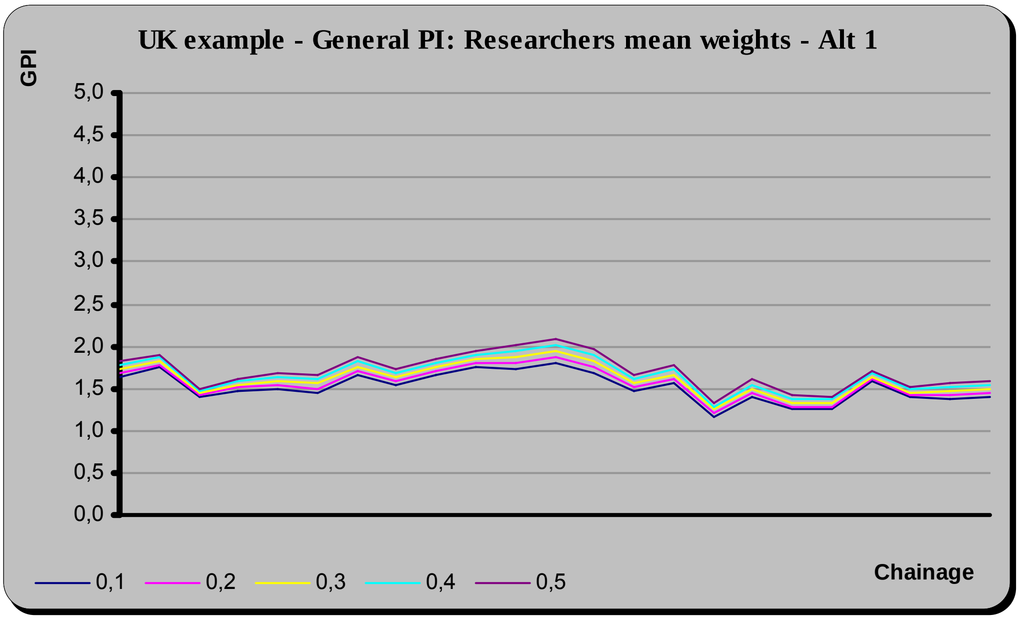
UK example - General PI: Researchers mean weights - Alt 1
GPI
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4,0
3,5
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2,5
2,0
1,5
1,0
0,5
0,0
Chainage
0,1
0,2
0,3
0,4
0,5


UK example - General PI: Researchers median weights - Alt 1
GPI
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
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0,1
0,2
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0,4
0,5
Chainage